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THESIS

AN ECONOMIC MODEL FOR THE REPLACEMENT AND MANAGEMENT OF NAVY VEHICLES

by

Dale M. W. Walker

and

Brian R. Silas

June 1984

Thesis Advisor: Shu S. Liao

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The Naval Facilities Engineering Command (NAVFACENGCOM) Command Management Guidance for FY-84 identified the need for an alternative to the twenty year old DOD-specified vehicle replacement criteria (age and mileage). This thesis identifies a model which structures the replacement decision as an examination of the economic balance between average annual costs of ownership and operation. The model is suggested for dynamic application in determining the optimal service lives of various vehicle types for fleet-wide replacement

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programming. It is also recommended as a tool for activity level transportation managers, since it provides a means to examine and compare the economic consequences of management policies and practices. Its practicality for this application is enhanced by the possibility that if implemented via the computer medium, it could be integrated with the electronic record keeping capability for public works transporation management currently being provided by NAVFACENGCOM's Project BEST.

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An Economic Model for the Replacement and Management of Navy Vehicles

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requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

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ABSTRACT

The Naval Facilities Engineering Command (NAVFACENGCOM) *Command Management Guidance* for FY-84 identified the need for an alternative to the twenty year old DOD-specified vehicle replacement criteria (age and mileage). This thesis identifies a model which structures the replacement decision as an examination of the economic balance between average annual costs of ownership and operation. The model is suggested for dynamic application in determining the optimal service lives of various vehicle types for fleet-wide replacement programming. It is also recommended as a tool for activity level transportation managers, since it provides a means to examine and compare the economic consequences of management policies and practices. Its practicality for this application is enhanced by the possibility that if implemented via the computer medium, it could be integrated with the electronic record keeping capability for public works transportation management currently being provided by NAVFACENGCOM's Project BEST.

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I. INTRODUCTION

A. THE NEED FOR A NEW VEHICLE REPLACEMENT POLICY

The Naval Facilities Engineering Command (NAVFACENGCOM) has responsibility in determining requirements, procuring, and assigning a family of equipment commonly referred to as Civil Engineering Support Equipment (CESE). This includes automotive vehicles, construction, railway, firefighting, and mobile weight handling equipment. Because these equipment have, for all practical purposes, finite lives, periodic replacement is required. In recent years the replacement of the Navy's CESE has suffered from a lack of support by Office of the Chief of Naval Operations (OPNAV) sponsors during the Navy's programming phase of the Department of Defense (DOD) Planning, Programming, and Budgeting System. This has resulted in the procurement of CESE at levels less than those recommended, extended the required life of this equipment beyond the current life expectancy criteria, and possibly driven the operating and maintenance funding requirements higher than anticipated. In order to obtain long term dollar commitments by OPNAV sponsors, the Commander of NAVFACENGCOM has delineated the need for "....developing a new, salable, and effective basis for the CESE replacement program, other than the 'overage' criteria currently used" [Ref. 1: p. 8].

Additional emphasis in this area was provided by a NAVFACENGCOM Inspector General (IG) audit performed at the Naval Construction Battalion Center, Port Hueneme, California in September 1983. Recommendation 83-215 proposed that the Civil Engineer Support Office (CESO), the organization within NAVFACENGCOM responsible for coordination of CESE replacement programming,

> ....in conjunction with NAVFACENGCOM (Codes 06, Deputy Commander for Military Readiness (SEABEES) and 10, Assistant Commander for Facilities and Transportation), explore the feasibility of developing a life cycle management model for automotive, construction, and special handling equipment that would include readiness factors, maintenance costs, retention, overage, acquisition costs, emergent technology and other variables as appropriate. [Ref. 2]

The primary objective of transportation management within the DOD is to provide optimum responsiveness, efficiency, and economy in support of the DOD mission. NAVFACENGCOM's interest in the development of a new basis for CESE replacement is to be able to clearly illustrate to the OPNAV sponsors, as well as others concerned, that failure to replace an equipment asset at the completion of its economic life will result in the use of excessive amounts of operating and maintenance funds by activities to allow for the asset's continued operation. Because the quantity of transportation equipment available to each activity, identified as its "allowance", is initially established and thereafter annually reviewed and validated based on approved justifiable requirements, the activity must fund the operating and maintenance costs necessary to keep the asset functional in order to maintain its availability for mission support. Not only is it possible that these costs become uneconomical over time due to increased maintenance and repair requirements, the level of responsiveness that can be achieved with this asset may be severely diminished due to an increase in downtime as it ages. This can result in a degradation of the activity's mission readiness capabilities.

B. THE REPLACEMENT DECISION

Simply stated, the objective of any replacement policy is to optimize the economic consequences of owning and operating an asset while maintaining established performance and safety requirements. For transportation equipment the basic costs entering into the equation in both the public and private sectors are the fixed cost of acquisition and the variable costs of operations, maintenance, and repairs.

For commercial enterprises, other factors such as the cost of insurance, the influence of advertising, tax considerations, trade-in values, and an asset's contribution to the generation of revenue in many cases also influence the replacement decision. Clingman states:

> ....from a financial viewpoint, a company should drive its cars as long as they are operable because the equipment annual cost becomes less the longer the car is driven. However, employee morale, corporate image and prestige, employee safety, reliability, and driver time lost due to excessive maintenance would rule out this possibility for most companies. Therefore, trade-in decisions are based on intangibles or difficult-to-quantify considerations as listed above. [Ref. 3]

Safety, reliability, and image, in terms of "pride and professionalism", are also of concern to the Navy, but status generally is not, as evidenced by the fact that most equipment is of a factory standard color and contains only minimum amenities. The Navy, like many commercial enterprises, has formally established replacement criteria for CESE. Though a vehicle may meet the replacement criteria, this does not ensure that it will be automatically or immediately replaced. As a practical matter, there is only one annual procurement cycle after approval of the budget and release of the appropriations. If insufficient funds are programmed and/or budgeted to replace all eligible assets, some vehicles will not be replaced. When this happens, an activity must coordinate with its Transportation Equipment Management Center (TEMC), in order to determine which of the eligible assets will actually be replaced.

TEMC's are organizations established to accomplish assigned centralized technical responsibilities for the transportation equipment program in administering the assignment, replacement, and disposal of transportation equipment, and providing technical advice and assistance in its maintenance and utilization. In the case of an inability to replace all eligible vehicles, the TEMC will determine the order of priority in which assets from each of its activities will be replaced.

C. SCOPE OF THE STUDY

This study explores the feasibility of implementing within the Navy's fleet management systems an economic based model for use in vehicle replacement decision-making. It is intended that this model would be used primarily by activity transportation managers as a basis for justifying their replacement requirements to their respective TEMC's. Consolidation of these requirements could then be passed up the programming chain-of command for use by the TEMC's to NAVFACENGCOM, to the OPNAV sponsors, and to Congress. In order to facilitate its use, the model must be understandable to those field level managers, yet be comprehensive enough to be used as a basis of documentation for the programming process to illustrate the ramifications of varying levels of transportation equipment procurement upon operations and maintenance funding and mission readiness.

Additionally, this study investigates the merits of the use of static established age and mileage criteria as currently employed, versus the merits of a dynamic, continually evolving process for vehicle replacement. It is hypothesized that although, through a centralized procurement system, a vehicle's acquisition cost is equal to all other like vehicles procured in a particular year, the current, consistently applied replacement policy may not be the most cost effective. This is due to differing labor rates and weather/environmental conditions in various regions of the country which impact upon a vehicle's operating and maintenance costs.

This study is limited in scope to an examination of administrative use vehicles which comprise approximately 62% of the total CESE fleet and, in particular, to sedans, station wagons, and 1/4 to 3/4 ton pickup trucks which constitute approximately 77% of the administrative vehicle fleet.

An administrative use vehicle is defined as "....a motor vehicle, usually of commercial design, assigned on the basis of formal authorization documents, to provide transportation support of an installation/activity." To provide further clarification of this definition, a commercially designed vehicle is "a vehicle designed to meet civilian requirements and used without major modifications by DOD activities for routine purposes in connection with the transportation of supplies, personnel, or equipment." [Ref. 4: p. A-1]

II. BACKGROUND

A. ORIGIN OF CURRENT DOD REPLACEMENT POLICY

The current DOD policy for the management, acquisition, and use of motor vehicles establishes the standard replacement criteria for commercially designed vehicles. These criteria are based on age and accumulated mileage variables, and also direct DOD components on the calculation and use of one-time repair limits. [Ref. 4: p. 12-5]

From authority vested by published instructions of the Secretary of the Navy, the Chief of Naval Operations and the Chief of Naval Material, NAVFACENGCOM has technical responsibility for the administration, operation and procurement of transportation equipment for the Navy. NAVFACENGCOM has provided guidelines for the management of this equipment [Ref. 5], which include the criteria for replacement in terms of the DOD age and accumulated mileage variables as well as the factors for the computation of cost repair limits. Sedans, station wagons and 1/4 to 3/4 ton pickup trucks are eligible for replacement when one of the following criteria has been met: (1) six years of age, (2) accumulation of 72,000 miles, or (3) when the one time cost of repairs exceeds 50 percent of the present replacement value of the vehicle as determined from the computation factors shown in Table I [Ref. 5: p. 10-1]. The present replacement value of a four year old vehicle, for example, is considered to be 42% of the current acquisition cost. One time repairs are limited to 50% of this amount.

The current criteria for vehicle replacement originated as the result of a study during the early 1960's of vehicle repair and replacement policy by staff members of the Office

TABLE I

COMPUTATION FACTORS FOR REPLACEMENT VALUES

Age in Years	1	2	3	4	5	6
Percentage of Equipment Replacement Cost	75	64	53	42	31	20

of Assistant Secretary of Defense, assisted by transportation representatives of the military services. Analysis of data from both the Government and private industry demonstrated that for each mile of vehicle use, a definite percentage of wear resulted under given operating conditions and maintenance procedures. It was therefore concluded that the interests of economy and efficiency could best be served by adopting an objective for planned replacement when certain mileage or condition factors (age or one time repair cost) were met. [Ref. 6: p. 44]

Prior to the establishment of these criteria vehicles were replaced when an inspector judged that a vehicle was worn out and worthy of replacement [Ref. 7: p. 3].

B. THEORETICAL REPLACEMENT MODELS

As an initial approach to the search for new replacement criteria, consideration was given to what the theoretical literature on replacement in general has to offer. It was reasoned that only through knowledge of what is available in theory, could a replacement model be identified or developed for practical application.

As summarized by Douglas, modern replacement theory began in 1923 with J. S. Taylor's theory of optimizing economic life by minimizing the unit cost of output. Harold Hotelling simplified the process by the use of continuous functions shortly thereafter, and in 1940, Dr. G. A. D. Preinreich advanced the theory that the immediate replacement decision was influenced by an infinite chain of successor replacements. George Terborgh, in 1949, put forth the idea of an "inferiority gradient"; a means by which the inferiority of an existing machine could be quantitatively measured against the relative superiority of a new potential replacement. In 1952, Dr. A. A. Alchain promoted in Rand Report R-224 the use of exponential curves to represent the behavior of input variables, facilitating an analog computer solution to the problem [Ref. 8: pp. 69-74, 101]

Subsequent writings have taken varied approaches to solving the replacement question: probabilistic or deterministic, continuous or discrete. Howard [Ref. 9: pp. 54-59, 89-91], for example, devised a system of analysis termed the "Policy-Iteration Method" which structures the problem as a Markovian chain decision. Douglas himself used Alchain's work as a basis for his examination of replacement timing for profit maximization in construction equipment operations. He too used exponential equations to model the forms various revenues and costs may take, but additionally allowed for the effects of taxes, inflation and variations in interest rates [Ref. 8: p. 75]. The final form of his computer-based model accepts as many as seventy variables and utilizes thirty-three equations [Ref. 10: p. 17].

C. REVIEW OF EMPIRICAL STUDIES

To determine how equipment replacement theory has been applied to real-world situations, a literature search was conducted to determine how empirical studies have approached the investigation of the replacement question and what findings resulted. Highlights of several which pertain specifically to the validity of criteria applied within DOD are provided below. Additionally, a General Accounting Office (GAO) report on the replacement of General Services Administration (GSA) sedans is examined since similar criteria are used for these vehicles.

The inclusion of these studies is thought to be beneficial in that it may help to acquaint the reader with the setting in which replacement decisions are made. Also, it is instructive to consider the various findings in that significantly different answers have been found to essentially the same question. No assessment is made as to the legitimacy of any particular approach or the validity of any findings. However, comment will be made subsequently regarding conclusions which may be drawn by considering these studies as a group.

1. DARCOM Study

This study [Ref. 11], completed in 1979, was commissioned by the Army's Development and Readiness Command (DARCOM) specifically to provide an update of the DOD-specified age and mileage criteria for administrative use vehicles. Statistical techniques of regression analysis were applied to summary maintenance data from major Army commands. Additionally, a special data collection effort covering six installations was used to collect some data items not included in the summary statistics. The data included direct labor man-hours, direct maintenance costs (direct labor and direct materials), vehicle shop days, miles driven per year and age in years.

Some general observations resulting from the data analyses were:

a. The average number of maintenance man-hours and costs increase up to the seventh year, then remain constant or decline through the tenth year. The hypotheses posed to explain these constant or declining trends were that they resulted from the application of the one-time repair expenditure limits to older vehicles, or from deferring maintenance on vehicles as they approached the time of their scheduled replacement. Since one objective of the study was to determine new criteria, removal of any bias in the data caused by application of the existing criteria was deemed necessary. This was accomplished by omitting the data for very old vehicles, and extending the previous rising linear trend through the later years. This trend was considered to provide a better estimator under changing policies for costs to operate older vehicles.

Another discovery from the analysis of data for maintenance concerned the effect of the intensity of usage during a period. It was determined that higher usage over a year's time resulted in correspondingly higher maintenance requirements.

b. It was reported that over at least the first nine years of a vehicle's life, no significant increase in shop days as age increased could be detected. Irrespective of the observation that shop days seemed to remain stable the study cautioned that an increase as a vehicle ages remained a possibility, resulting in a need to establish a service life lower than the established economic life. When establishing the economic lives of the ten types of vehicles for which adequate data were available, no account was given in this study to any penalty (opportunity cost etc.) for lost availability due to time in the shop. Should an increase in shop days in reality occur, the inclusion of such a penalty charge based on increasing downtime would drive the service life even lower.

With the caution that the effects of the one-time repair expenditure limit on yearly average lives could not be predicted, new vehicle economic lives based on the study results were presented as shown in Table II . While the results were reported to provide a good basis for fleet cost prediction, they were not claimed to be a good individual vehicle cost predictors.

The recommendation was made that an adoption of the extended vehicle lives should be accompanied by an adoption of a new method for calculating repair expenditure limits, also developed as part of the study. Since these limits would lead to the replacement of some vehicles before the expiration of their computed economic lives, further study would be required to determine the effect these limits would have on total fleet replacement policy.

2. Reidy and Schneider Study

This 1974 master's thesis [Ref. 12] set out to examine the validity of the DOD age/mileage replacement criteria, focusing on light sedans, station wagons and pickup trucks. The initial tack taken was to poll various commercial companies and governmental agencies to determine what procedures, analyses, variables and factors they used to decide when to replace a vehicle. Included were agencies of federal and local governments, auto manufacturers, leasing and fleet management companies, utilities, taxi operators and research organizations.

It was found that age and mileage criteria were the ones most consistently used by the organizations polled, and the ones most frequently stated explicitly as the bases for at least a quasi-formal policy. To varying degrees, replacement decisions were also found to have been influenced by maintenance and operating costs, and by downtime and obsolescence. Criteria based on these factors were generally not spelled out in the form of a formal policy, but were only subjectively applied as the decision-maker deemed appropriate to the situation.

TABLE II

DARCOM REVISED VEHICLE LIFE EXPECTANCIES

VEHICLE TYPE	AGE IN YEARS DOD	REV	DIF	AGE IN MILEAGE DOD	REV	DIF
Auto, Sedan Compact (1)	6	6	0	72,000	80,000	+ 8,000
Truck, 1/2 T Cargo	6	13	+ 7	72,000	120,000	+48,000
Truck, 1 T Cargo	7	7	0	84,000	75,000	- 9,000
Truck, 1/2 T Carryall	6	13	+ 7	72,000	120,000	+48,000
Truck, 1/2 T Panel	6	12	+ 6	72,000	120,000	+48,000
Truck, 1 T Stake (2)	7	9	+ 2	84,000	80,000	- 8,000
Truck, 5 T Stake	10	20	+10	150,000	130,000	-20,000
Truck, Tractor	10	20	+10	150,000	175,000	+25,000
Truck, Utility 4X2	6	9	+ 3	72,000	110,000	+38,000
Truck, Utility 4X4	6	9	+ 3	72,000	115,000	+43,000

(1) Some four year old vehicles of the same manufacturer had very high costs.

(2) Large increase noted in shop days for eight year olds.

Age and mileage were major considerations for leasing and fleet management organizations, but were applied more in view of currency of body styles or physical appearance than in regard to simply minimizing ownership and operating costs. While a governmental agency would be concerned in minimizing costs, these organizations were influenced in their decisions by a vehicle's continued ability to maintain consumer appeal and offset costs by generating profits. Thus, the economic decision to replace was made at a point sooner than if costs alone were considered.

Two commercial activities, Eastern Air Lines and Bell Laboratories, were reported to have been developing scientific, computer-based decision models and information systems for vehicle management. Efforts as part of the research for this thesis to determine the present status of those systems found that the Operations Analysis Applications Group of Bell Labs, the group responsible for designing that company's system, has apparently been disbanded. Attempts to determine if the Bell Labs model was put to use were unsuccessful. Contact with the office responsible for ground transportation replacement at Eastern Air Lines indicated that no computer-based system is now in use (or for that matter, even known to exist). As in the past, target ages for replacement of various vehicle types are used as a rule of thumb. A decision to replace an individual vehicle sooner or later than the target age for that particular type is subjectively made, based generally on that vehicle's conformance to cost norms.

After finding the replacement criteria used by commercial and other governmental agencies to be generally the same as, or no better than, those of the Air Force (thus DOD as a whole), Reidy and Schneider turned to the application of regression analysis of historical vehicle data from two of that agency's commands, to determine if the DOD criteria were valid.

For the groups of vehicles examined, it was reported that vehicle age was not a statistically significant predictor for cost per mile to operate, or for direct labor maintenance manhours required. Further, there was no indication that out-of-commission rates or down-for-parts rates increased significantly once a vehicle exceeded six years of age. Some statistical significance was said to have been found only in an increase in direct labor maintenance manhours for vehicles driven in excess of 72,000 miles.

3. GAO Study

This 1979 study [Ref. 13] examined the 30+ year old GSA criteria specifying replacement of sedans upon reaching six years of age or 60,000 miles of usage. These criteria were applicable to the 42,000 sedans in the GSA interagency motor pool and, by regulation, to the 22,000 other sedans operated by other federal civilian agencies.

The study considered the costs of depreciation, preparation (upon acquisition), selling (upon disposal), maintenance, repair and interest on capitalization. Several methods of analysis were applied under various assumptions to evaluate replacement cycles of from one to six years. The results showed that a one-year cycle provided the lowest annual cost option. This was believed to be the case because maintenance costs were thought to be lowest during the first year of operation. Also, the large depreciation in a vehicle's resale value normally expected during the first year tends to be offset somewhat in the government's case by lower purchase prices resulting from bulk buys.

In a summary of previous reports, it was noted that shortened replacement cycles of between one and four years had been recommended by ten GSA or GAO studies conducted since 1954, including four conducted during the 1970's. It is interesting to note that while all agreed that the six-year cycle was too long, there apparently was no consensus as to what the economic replacement cycle should be. Also noteworthy is that while this 1979 GAO study concluded that a one-year cycle would be the most economical, the second most economical choice would be a four-year cycle under most assumptions. Therefore, if the vehicles were not replaced at the end of the first year, it would be most economical to then wait until the end of the fourth year for replacement.

4. Brooks and Bulen Study

This 1969 master's thesis [Ref. 14] was initiated to study the validity of a then-proposed change in the application of age and mileage criteria by the Department of the Air Force. Previously, exceeding the maximum age or the maximum mileage had signaled the point at which a vehicle was due to be replaced. The proposed change was for both criteria to be exceeded before a replacement action could be initiated. The study intended to determine if combinations of less than the maximums of both criteria could provide economic justification for replacement decisions.

Considering vehicle acquisition and repair costs for one major Air Force command, regression analysis was applied to determine the point at which the average total cost of ownership was minimized, at which time a vehicle's economic life was considered to have been reached. This point, as determined in the study, is shown in Table III for the six vehicle types considered. In addition to determining economic life based on age or mileage, a regression equation was developed for each vehicle type. Including both variables, this equation was intended to be used to determine the economic replacement point for various combinations of those variables.

TABLE III

BROOKS/BULEN REVISED VEHICLE LIFE EXPECTANCIES

VEHICLE TYPE	AGE IN YEARS DOD	 REV	 DIF	AGE IN MILEAGE DOD	 REV	 DIF
Sedan, Light	6	5.25	- .75	72,000	70,500	- 1,500
Station Wagon	6	5.58	- .42	72,000	85,400	+13,400
Truck, Multi-Stop	7	6.58	- .42	84,000	43,400	-40,600
Truck, Cargo 2 Dr (4,800 GVW)	6	5.42	- .58	72,000	83,400	+11,400
Truck, Cargo 4 Dr, (4,800 GVW)	6	7.00	+1.00	72,000	73,800	+ 1,800
Truck, 1-1/2 T Stake (14,000 GVW)	7	8.33	+1.33	84,000	60,200	-23,800

5. Kiesling Study

This 1980 master's thesis [Ref. 15] sought to to determine the economic life of Navy sedans using average depreciation, operating and maintenance costs reported by the Hertz Corporation and the Department of Transportation, adjusted to better reflect Navy experience. It concluded that average costs to own and operate an automobile would decrease through the sixth year of ownership. At that time, major maintenance would be required to recondition the vehicle. Thereafter, average costs would continue to decline at least through the tenth year.

From this, it was surmised that the sixth year of ownership represented a logical point at which to evaluate the replacement decision. If the vehicle was in relatively good shape with respect to condition, safety and reliability, it should receive the major maintenance and be retained through the tenth year. If not, it should be immediately replaced.

6. Klungle Study

This 1969 master's thesis [Ref. 7] was initiated to determine both the economic life of the Navy's fleet of pickup trucks and the proper criteria for one-time repair expense limitations. It was based on historical Navy and GSA data for acquisition costs, maintenance expenses and downtime. "Truck Blue Book" values were used to estimate the expected loss of salvage value of a truck. Through analysis, a rising linear trend with respect to age was found to closely approximate the expected maintenance costs through about seven years of operation. A rising linear trend with a high correlation was also found for downtime rates through at least twelve years.

Based on these trends, the economic life of a pickup truck was determined under varying assumptions of expense rates (maintenance), salvage values and interest on capitalization. The results for combinations of these assumptions varied between economic lives of one and nine years. The effect of salvage values was the most dramatic, changing the decision point by as much as seven years (a longer cycle being associated with using a "no salvage" assumption versus "Truck Blue Book" salvage values).

Under the combination of assumptions considered in the study as most likely to approximate the Navy's situation ("no salvage" case, 5% discount rate, linearly rising maintenance expenses), a seven-year replacement cycle was found to be optimal. Based on the data and calculations, the difference between this cycle and the specified six-year cycle represented an additional cost per vehicle of $7 per year. Between cycles of from six to nine years, the widest difference resulted in an additional cost of less than $10. This indicated that decision-makers could have a relatively wide latitude in making the replacement decision without significant economic consequences.

III. SELECTION OF A REPLACEMENT MODEL FOR NAVY VEHICLES

A. INFLUENCE OF EMPIRICAL STUDIES

The preceding chapter highlighted the approaches taken and conclusions reached in some previous studies of the replacement question. Several used summary vehicle cost data to analyze the validity of replacement criteria. Others incorporated an effort to collect detailed data from various sources. With the exception of the GAO study of GSA sedans, they all considered the validity of the DOD-specified criteria, for example, replacement after six years of age or 72,000 miles of use for sedans and pickup trucks.

All studies reached some conclusion regarding the legitimacy of these criteria, but there was little consistency among them. Some said the DOD criteria required replacement of vehicles too soon, others said too late, and still others said the DOD criteria were about right. Since the variability of the conclusions seem somewhat curious, closer examination of some possibilities that may account for the variations is necessary.

1. Timing Differences Between Studies

The studies used data from periods as early as the mid-1960's, through periods as late as the latter-1970's. With such a range in time, variations in costs would, of course, result from a continuing inflationary trend. However it is the relative variation in costs within a replacement model which determines the outcome of the replacement decision; the balance between the costs of ownership and the costs of operation which may not vary in direct relation with one another.

Klungle reported that in the years 1961-1969, the purchase price of Navy pickup trucks varied by only $ 20, and even dropped in some years [Ref. 7: p. 15]. This occured irrespective of an overall increase in the national consumer price index of about 10%. Reidy and Schneider reported that for the city of San Francisco, during the early 1970's, the purchase price of vehicles had increased 70% over a period of several years while the wages of maintenance mechanics had increased 143% [Ref. 12: p. 72]. The purpose in citing these observations is to illustrate that the economics of the model may or may not conform to economic conditions in general, and that they can vary significantly within the model.

Differences in timing may have come into play in leading the various studies to differing conclusions, of which any may have been valid for the time. However, the fact that the replacement question will be influenced continually by various and changing factors should condemn the application of static criteria.

2. Cost Experience Differences Between Agencies

Though DOD replacement criteria are specified for use by all service components, the services are given flexibility in establishing vehicle maintenance staffing levels and procedures. This has led, however, in some cases to significant differences between the services in the management of their vehicle fleets. A recent GAO report [Ref. 16: pp. 2-3] stated that one service's staffing methods result in a personnel-to-vehicle ratio almost twice that resulting from the standards of another service.

Differences such as this could have easily led to varying conclusions being reached by the different studies. Due to the separability of the services' missions and requirements, no inference is drawn herein that they should be constrained to follow identical policies. However, a criticism may be applied against the economic soundness of specifying service-wide criteria which ignore the variations which exist.

3. Differences in Model Inputs and Form

There was some variation within the studies regarding the types of cost data considered in the analyses. Where one may have included administrative costs associated with vehicle procurements, another did not. One may have imputed some cost for downtime impact while another considered only directly measurable costs. In many cases, legitimate costs may have been ignored due to inaccessibility of data, either because the data were not in a form which allowed the costs to be determined or they were not available at all. By a study ignoring one or more of the data items influencing the replacement decision, a bias would have been introduced into the results of that study's analysis, its magnitude depending on the relative influence of the item.

Another possible cause of variation in the results of the studies would be differences in the form of the models used to determine the validity of the DOD criteria. An analysis of these differences is not made herein. However, it is worth noting that the studies were for the most part similar in that replacement decisions were related to determinations of long-run minimum average total costs.

From this discussion of differences between findings in the previous studies, some conclusions may be drawn which should serve as guides for any replacement model applied within the Navy environment.

The changing economics of the replacement issue requires the dynamic application of a decision model; that is, it should be applied on a continuing basis so that criteria may be updated whenever the balance between operating costs and ownership costs shifts significantly. To restrict replacement decisions to static criteria is to ignore the influences of an ever-changing world. Also, the criteria should not be forced to serve applications for which they are inappropriate. To apply them to too broad an environment is to ignore the unique economics of the various situations which may exist.

If the correct conclusions are to be drawn from the model, the input data must include all costs which will influence the replacement decision. The literature is consistent in stating that input data must be accurate if the right decision is to be reached. Failing to include some cost for the impact of downtime, for example, could have significant consequences. The services have set goals for downtime not to exceed 10%, and even at this rate a vehicle will be out of service for more than one month in a year. Consider the mission impact when downtime, as reported for an activity of one service, reached 33% during one month.

At the outset of this research effort, intentions had been to follow the same course as the previous studies. This approach would have seen large amounts of vehicle data assembled, to which regression and other techniques of analysis would have been applied. This effort would have led to the determination of new replacement criteria which could have then been compared to the DOD standards. Two obstacles stood in the way of this approach.

First, cost records at activity or higher levels are kept in neither the detail necessary nor in the form required to have allowed this effort to be completed within the time available. Second, it became apparent as more insight into the subject was gained that any new criteria which may have been determined would have been valid only for a particular moment in time.

If any one broad criticism may be aimed at the outcome of studies which previously have developed new age and mileage criteria, it is that these criteria are only the product of the data available at the time the studies were conducted. These revised criteria are as locked in the past as are the current DOD-specified criteria. The authors of the studies themselves frequently recognized this to be so, and recommended that systems be established whereby criteria would continually be examined and updated. Where any one set of criteria may have been valid in its time, its applicability to the economics of today or those of tomorrow is questionable.

This is not to say that one set may not yet be appropriate for use in today's world, and another in tomorrow's. It is certain, though, that all cannot legitimately coexist, so the question remains: which can you rely upon for the correct decision? The path to the answer leads to the necessity for a replacement decision model which can be applied in a dynamic environment.

E. CONSIDERATIONS AND PROPOSAL FOR A MODEL

Numerous literature sources exist today which deal in one form or another with the replacement question. Many of these exist within the fields of engineering economics and operations research. The methods offered by these sources for structuring replacement decisions are frequently quite elaborate, some relying on the establishment of probability predictions of equipment cost characteristics to guide the decision-maker.

When in the face of existing theory the selection of a practical model for Navy vehicle fleet managers was considered for this thesis, procedures based on the use of continuous functions were believed to be impractical. While possibly appealing theoretically, they were thought to be conceptually too complex to be widely understood and as a result, would find little continuing practical application. A model which measures inputs and reports outputs in discrete forms would seem more appealing due to a promise of more ready acceptance. To the extent that a discrete model satisfies those characteristics required to give a model credibility, it would therefore hold an advantage.

Another choice regarding the form of a model is whether it is probabilistic or deterministic. With either, the quality of the output will depend upon the quality of the required input data available. As discussed subsequently, current availability of data in the format necessary for the employment of an economic model is a problem. Given that a deterministic model is otherwise valid, it would appear to be more appropriate in this case since the data requirements of a probabilistic model would be more severe. In any case, probabilistic elements could subsequently be introduced into a deterministic model as necessary data became available.

In 1949, George Terborgh, writing on behalf of the Machine and Allied Products Institute, gave a detailed accounting of the equipment replacement problem. In his work, "Dynamic Equipment Policy" [Ref. 17], he employed a model based on the conversion of periodic costs into uniform annual equivalents, or periodic average costs, to facilitate analyses and comparisons. As structured by Terborgh, the model is both deterministic and discrete in nature. The principle upon which it is based, use of discounted cash flow methods to determine average annual costs, is well grounded in replacement theory; indeed, Terborgh's work serves as a basis for much of the theory existing today.

The function of the model is to compute time-adjusted averages for combined ownership (capital) costs and operation (operating and maintenance) costs. These averages are computed for any period by first finding the present value of all costs through that period. The second step is to determine an annuity amount (assuming annual periods) which, if paid each period through the period in question, would yield a present value equal to that calculated using the actual costs. The use of averages smooths out the effects of timing on cash flows, and allows the consequences of retaining a machine for varying periods to be more readily known.

In comparison with other methodologies available, that employed by Terborgh seems well-suited to the Navy's needs since it maintains the simplicity necessary for practical application, yet remains theoretically sound. The remainder of this chapter describes the structure of the methodology in Terborgh's model, and discusses the model's suitability within the context of the requirements expected of a credible model.

C. STRUCTURE OF THE MODEL

Using hypothetical vehicle cost data, Tables IV, V, and VI provide a "spreadsheet" format to demonstrate the methodology employed by Terborgh for converting actual periodic costs into periodic (or annual) average costs. Table IV concerns itself with operating and maintenance-type costs, while Table V addresses ownership costs: acquisition capital (in this example a $10,000 purchase price) and costs associated with maintaining that capital thereafter. Table VI combines the data from the previous two tables in addressing total costs (Note: the tables contain some slight rounding errors).

In Table IV, Column (Col) OM2 represents in current dollars the amount of the hypothetical operating and maintenance costs incurred in each period. By multiplying a

TABLE IV

OPERATING AND MAINTENANCE COSTS

OM1	OM2	OM3	OM4	OM5	OM6	OM7
1	750	0.9091	682	682	0.9091	750
2	1,119	0.8264	925	1,607	1.7355	926
3	1,774	0.7513	1,333	2,940	2.4869	1,182
4	2,003	0.6830	1,368	4,308	3.1699	1,359
5	2,589	0.6209	1,608	5,916	3.7908	1,561
6	2,947	0.5645	1,664	7,580	4.3553	1,740
7	3,412	0.5132	1,751	9,331	4.8684	1,917
8	3,878	0.4665	1,809	11,140	5.3349	2,088
9	4,223	0.4241	1,791	12,931	5.7590	2,245
10	4,657	0.3855	1,795	14,726	6.1446	2,397
11	4,998	0.3505	1,752	16,478	6.4951	2,537
12	5,411	0.3186	1,724	18,202	6.8137	2,671

CM1- Period (discount rate used assumes yearly period in this example)
CM2- $ Operation and Maintenance Costs for Period
CM3- Present Value Factor for $1 @ 10% Discount Rate
CM4- $ Present Value of Operation and Maintenance Costs for Period (OM2 X OM3)
CM5- $ Present Value of Operation and Maintenance Costs thru Period (CM4 cumulated)
OM6- Present Value Factor for Annuity of $1 in Arrears @ 10% Discount Rate
CM7- $ Average Annual Operations and Maintenance Costs (CC5 / CC6)

period's cost by its correlated present value factor (Col OM3), these costs are converted in Col OM4 into present value equivalents (all costs in "Period 0" terms) reconciling cash flows from different time periods with one another. By cumulating these adjusted costs in Col OM5, a present value for all cash flows through the period indicated is obtained.

By then dividing these amounts by the annuity factors in Col OM6, annual average costs in current dollars through the various periods are determined as shown in Col OM7. This means, for example, that the actual cash flow amounts for operating and maintenance costs through Period 7 ($750; $1,119; $1,774; $2,003; $2,589; $2,947 and $3,412) are equivalent to having incurred a uniform cost of $1,917 in each of Periods 1 through 7; that is, either cash flow will yield the same present value when discounted at the stated rate. Figure 3.1 graphs the average operating and maintenance costs from Col OM7 against the periods. This graph shows the rising trend in operating and maintenance costs over time which was determined by several of the empirical studies and is described in much of the literature.

In Table V, a similar methodology is employed to determine the average annual costs of ownership (capital and capital maintenance costs). Col CC2 lists the salvage value of the vehicle at the end of a period. The difference between this value and that at the beginning of the period (value for previous period in Col CC2) represents the loss of value during the period. This is a cost of ownership since this loss is incurred by choosing to keep the vehicle for another period when it may be sold for the ending salvage value, as opposed to selling it at the beginning of the period for the higher salvage value. In short, it represents the value "used up" during a period. Costs due to loss of value are shown in Col CC3.

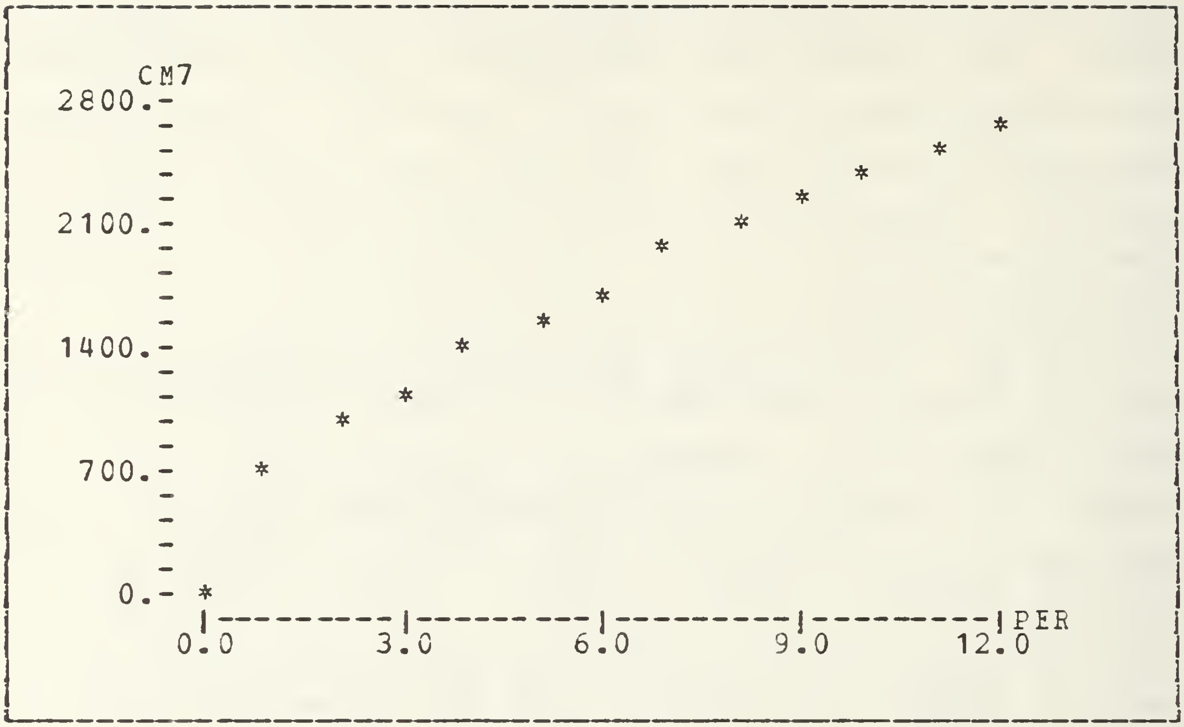


Figure 3.1 Operating and Maintenance Costs.

Col CC4 represents what in the private sector would be the interest cost for continuing to utilize borrowed capital to own the vehicle for another period (charged at a stated rate on the salvage value at the beginning of a period). Agencies of the government do not, of course, finance the purchase of new vehicles through loans. Government funds are generated through tax receipts and the sale of government securities, and are appropriated by the Congress to the various federal agencies and components. In applying the methodology within the Navy's environment, this cost may be considered to represent a cost of foregoing the opportunity for alternative uses to which these funds might be placed. A rate of 10% is used in this example for charging opportunity cost and discounting as specified for use by the Office of Management and Budget. A subsequent chapter on model inputs will address the rate in more depth.

TABLE V

CAPITAL (OWNERSHIP) COSTS ($10,000 ACQUISITION VALUE)

CC1	CC2	CC3	CC4	CC5	CC6	CC7	CC8	CC9	CC10
1	7,500	2,500	1,000	3,500	0.9091	3,182	3,182	0.9091	3,500
2	5,625	1,875	750	2,625	0.8264	2,169	5,351	1.7355	3,083
3	4,219	1,406	563	1,969	0.7513	1,479	6,830	2.4869	2,746
4	3,164	1,055	422	1,477	0.6830	1,009	7,838	3.1699	2,473
5	2,373	791	316	1,107	0.6209	687	8,526	3.7908	2,249
6	1,780	593	237	830	0.5645	469	8,995	4.3553	2,066
7	1,335	445	178	623	0.5132	320	9,314	4.8684	1,913
8	1,001	334	134	468	0.4665	218	9,533	5.3349	1,787
9	751	250	100	350	0.4241	148	9,681	5.7590	1,681
10	563	188	75	263	0.3855	101	9,782	6.1446	1,592
11	422	141	56	197	0.3505	69	9,852	6.4951	1,516
12	317	105	42	147	0.3186	47	9,898	6.8137	1,453

CC1- Period (discount rate used assumes yearly period in this example)
CC2- $ Salvage Value at End of Period
CC3- $ Loss of Salvage Value During Period (Previous CC2 - CC2)
CC4- $ Opportunity Cost Charge against Salvage Value at Beginning of Period (10% of Previous CC2)
CC5- $ Total Capital Cost for Period (CC3 + CC4)
CC6- Present Value Factor for $1 @ 10% Discount Rate
CC7- $ Present Value of Capital Cost for Period (CC5 X CC6)
CC8- $ Present Value of Capital Cost thru Period (CC6 cumulated)
CC9- Present Value Factor for Annuity of $1 in Arrears @ 10% Discount Rate
CC10-$ Average Annual Capital Cost (CC8 / CC9)

Col CC5, the sum of the previous two, represents the total cost of ownership in each period. Cols CC6 through CC9 apply the same methodology used in the previous table (in Cols OM3 through OM6) to convert periodic costs in current dollars to the annual average capital costs listed in Col CC10. These costs are graphed in Figure 3.2 . This graph shows a trend which decreases over time at a decreasing rate.

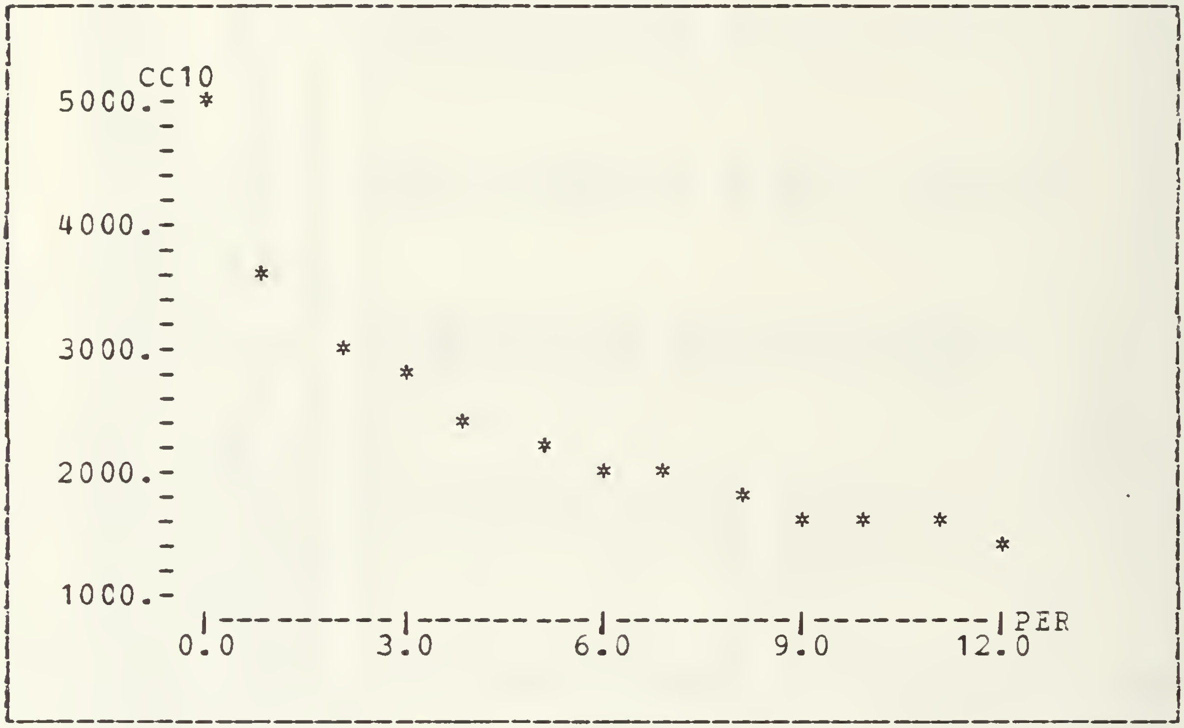


Figure 3.2 Capital (Ownership) Costs.

In Table VI, periodic costs from the previous two tables (Cols OM2 and CC5) are summed into Col TO2. This represents the total cost of ownership and operation in a period. Cols TO3 through TO6 again employ the methodology necessary to convert the periodic costs into average annual total costs, shown in Col TO7. Alternatively, Col TO7 could have been derived by simply summing Cols OM7 and CC10 for each period

TABLE VI

TOTAL CAPITAL, OPERATING AND MAINTENANCE COSTS

TO1	TO2	TO3	TO4	TO5	TO6	TO7	
1	4,250	0.9091	3,863	3,863	0.9091	4,250	
2	3,744	0.8264	3,094	6,957	1.7355	4,009	
3	3,743	0.7513	2,812	9,769	2.4869	3,928	
4	3,480	0.6830	2,377	12,146	3.1699	3,832	
5	3,696	0.6209	2,295	14,441	3.7908	3,810	
6	3,777	0.5645	2,132	16,573	4.3553	3,806	**
7	4,035	0.5132	2,071	18,644	4.8684	3,830	
8	4,346	0.4665	2,027	20,671	5.3349	3,875	
9	4,573	0.4241	1,939	22,610	5.7590	3,926	
10	4,920	0.3855	1,897	24,507	6.1446	3,989	
11	5,195	0.3505	1,821	26,328	6.4951	4,053	
12	5,558	0.3186	1,771	28,099	6.8137	4,124	

TO1-   Period (yearly period assumed)
TO2- $ Total Costs for Period (OM2 + CC5)
TO3-   Present Value Factor for $1 @ 10% Discount Rate
TO4- $ Present Value of Total Costs for Period (TO2 X TO3)
TO5- $ Present Value of Total Costs thru Period (TO4 cumulated)
TO6-   Present Value Factor for Annuity of $1 in Arrears @ 10% Discount Rate
TO7- $ Average Annual Total Cost (TO5 / TO6)
(Note: TO7 could be obtained directly by adding OM7 and CC10)

** Period Minimizing Lowest Average Annual Costs since these columns are already converted into annual averages for their respective cost components. In this hypothetical example, total average costs reach a minimum in Period 6 of $3,806. Figure 3.3 combines the previous two graphs and includes their sum, the total average cost curve which is a plot of Col T07 costs. This curve declines initially due to the influence of decreasing capital costs, then rises as it is driven upward by the increasing costs of operation. The minimum point on this curve corresponds to the period in which average total costs are minimized (Period 6).

Reference to Col T07 in Table VI will provide some examples of the information available to the decision-maker through use of the model. First, the optimal service life of the vehicle in this example would be six years. That is, the period in which this vehicle should be traded to optimize costs is the period in which average annual total costs are minimized (given that it could be replaced then with a vehicle no more costly to own and operate, and that a more economical vehicle is not available sooner). Also, the table shows that retaining this vehicle through eight years, for example, would cost an average of $69 ($3,875 - $3,806) per year of ownership more than if it had been replaced at the point of its optimal service life.

It may be noted that the present value annuity factor used herein assumes that all costs are incurred at the end of a period. This is merely a convention employed to reduce the complexity of the model. Other factors could be used to compute average costs as though periodic costs were incurred at the middle of the period (or any other time, for that matter). However, it is doubtful that the use any other convention would significantly improve the results of the model given the degree of accuracy with which some input costs (such as salvage values) could be determined.

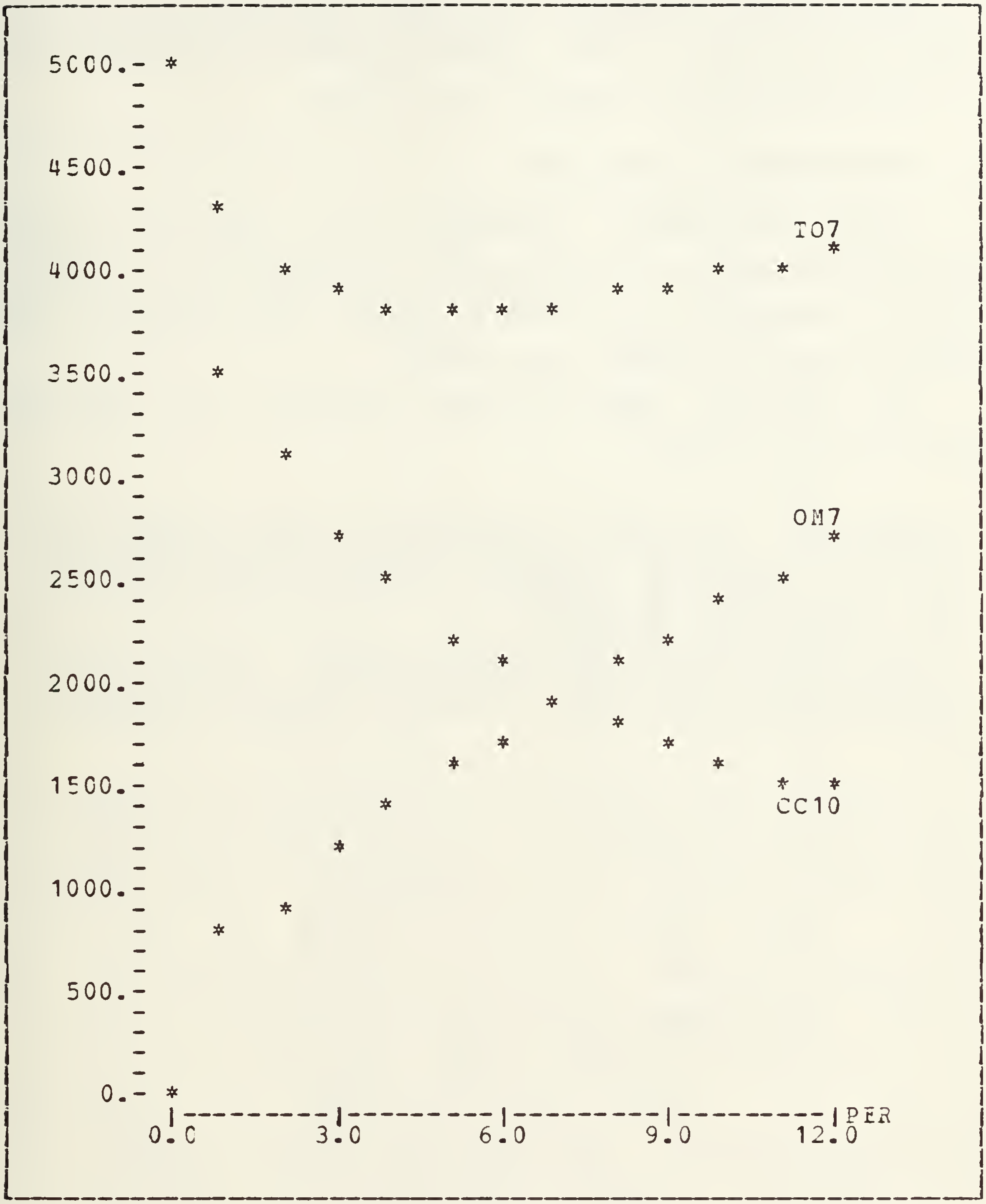


Figure 3.3 Total Capital, Operating and Maintenance Costs.

The mathematics behind the model are shown for information in Figure 3.4. This figure presents the equation for the determination of average total costs.

D. SUITABILITY OF THE MODEL

Before the model's legitimacy as an aid to informed decision-making can be established, an examination is necessary to determine its validity within the context of the elements required of any good model.

One financial analysis guide provides the following definition of a model:

> A model is a simplified representation of a real-world phenomenon. It is an abstraction or generalization of reality. In finance, a model is almost always mathematical and, therefore, specifies the relationships among a set of variables in the hope of describing or explaining the system being studied....
> ....Proper use of a model will permit isolation of the variables deserving the most attention. Additionally, if the model is properly specified, information can be generated that will lead to more effective decisions. [Ref. 18: p. 281]

A model by this definition is then a means to visualize some real-life situation in a simplified way that leads to better understanding of its complexities. This describes what is herein being sought in answer to the vehicle replacement question: a means by which relevant facts and data can be assembled to portray the reality of the situation in an easily examined form. Necessary for the suitability of a model are at least the following characteristics which determine its relative desireability and usefulness:

- Quality: A model should first of all present an accurate representation of the real-world situation under study. It should be capable of capturing at least the most significant aspects of the system or process and facilitate

$$ATC_n = \sum_{t=1}^{n} \left[\left[C(t) + S(t) + i \left[A - \sum_{t=1}^{n-1} S(t) \right] \right] \frac{1}{(1+r)^t} \right] \div \frac{1-(1+r)^{-n}}{r}$$

ATC_n = Average Total Cost Through Period n

$C(t)$ = Operating and Maintenance Costs in Period t

$S(t)$ = Loss of Salvage Value during Period t

i = Interest Rate on Borrowed Capital

A = Acquisition Value

r = Discount Rate

$\frac{1}{(1+r)^t}$ = Present Value Factor for \$1 in Period t

$\frac{1-(1+r)^{-n}}{r}$ = Present Value Factor for Annuity of \$1 in Arrears through Period n

Figure 3.4 Average Total Cost Equation.

their quantification in a directly comparable form to the extent they are commensurable. In short, it should solve the right problem.

The objective of the Terborgh model is to convert the opposing trends of decreasing ownership costs and increasing operation costs to terms that facilitate comprehension and allow comparison; in this case, average annual costs. Conceding that this is a valid means of comparison as justified by its appearance in literature addressing economic analyses, particularly those considering the vehicle replacement question (for example see [Ref. 10: pp. 6-8, Ref. 19: pp. 16-17, Ref. 20: pp. 70-74, and Ref. 21: pp. 3B-1-3B-2]), it meets this criterion.

An additional element of legitimacy is provided this methodology (or variations of it) in that it has found practical application in real life by fleet managers in municipal government agencies. Accounting for this may be the fact that as opposed to more complex approaches taken to the problem in operations research oriented literature, this method may be more easily understood at a practical level and thus stand more chance of being received in practice. Actually, it is only a structured format which employs principles, such as discounted cash flow, with which many managers are already familiar. If the model is otherwise theoretically tenable, strong weight should be afforded its potential for actual application and use.

- Simplicity: Though this requirement is seemingly at odds with the one previous, a usable model cannot be so complex as to become obscure. Its purpose, after all, is to reduce a complex set of circumstances to manageable terms. If it attempts to capture too many features of the system, it becomes cumbersome and of dubious value. Understanding of the system should not be clouded by the inclusion of variables which are of little relevance.

If it is conceded that the methodology being considered herein presents the economics of the replacement question in a logical and comprehensible way, satisfaction of this requirement then becomes a management issue of deciding what costs to include and in how much detail to include them. Since input data are received and results are reported in dollar terms, consideration must be given as to how to accommodate legitimate, though hidden or intangible expenses.

For example, an activity's mission will suffer and an impact cost will be incurred if due to a vehicle being in the shop, the performance of some mission is delayed. Obviously the quantification of this cost is no simple undertaking, but it is genuine and should somehow be imputed into the model. The allocation of indirect maintenance costs which vary with direct costs presents no less of a challenge. In the final analysis, simplification of the model reduces for the most part to a consideration of the form and detail of the input costs.

- Flexibility: A model should be structured such that its various features may be included as separate pieces of the whole. This allows the behavior of various variables to be examined and facilitates observation of the effects on the outcome resulting from the alteration of any particular variable. Within the context of this model, this criterion is as much as anything a matter of physical structure and format.

The tables previously used to demonstrate the structure of the model utilize a spreadsheet format. This format (as opposed to perhaps presenting the model in the form of an equation) allows the user to see input data, intermediate calculations and output results in a consolidated report. During successive iterations of solving the model, various input data could be altered and the resulting variations could be observed as the solution process progressed. If desired, inputs such as operating and maintenance costs could be broken down into greater detail to show trends in the various input components. Through such manipulations, a flexible model would be produced that would still allow the user to observe the methodology in progress.

- Data Availability: The right answer based on the wrong input data is of no more value than the wrong answer from the right data. If the correct data is not directly or immediately available, the efforts to obtain it must be justified by the ultimate use to which it will be put. Previous discussion addressed the problem of data availability. A subsequent chapter will include a consideration of how this problem promises to be reduced through the introduction of new technology into the Navy's transportation management environment.

IV. APPLYING MODEL IN THEORY AND PRACTICE

The mechanics of the proposed model having been explained, consideration is turned toward ways in which it may find application. This chapter first looks at how Terborgh originally envisioned its theoretical use, then examines some uses it has found in practice. The chapter concludes with a consideration of how theory and practice interact in implementing the model.

A. THEORETICAL APPLICATION OF THE MODEL

Terborgh used the model as a means to address the problem of equipment replacement, which he described as a challenge between an existing machine termed a "defender", and the best potential replacement machine called a "challenger." In his "Dynamic Equipment Policy" [Ref. 17], he developed a procedure whereby a machine incumbent in a job defended its position under economic examination against the challenge of the potential replacement. If successful, the incumbent remained in service. If not, it would be replaced by the challenger. The premise of this procedure is that economic decisions to replace or retain should be based on a comparison between the minimum average total costs of the challenger machine and the existing defender.

Two conditions are implicit in using this procedure for analysis and replacement decisions. They are: 1) average ownership costs will decline in successive periods since high initial acquisition costs are spread over a longer period of time, and 2) operating and maintenance costs will rise over time resulting in successively higher averages for these costs. The result is that average total costs for a machine initially decline owing to the spread of acquisition costs, then are driven up by rising operation costs as was shown graphically in Figure 3.3.

Terborgh used the theoretical minimum of average total costs as a means by which replacement decisions could be made. Assuming that minimum average total costs can be determined for both a defender machine and its challenger, the comparison between these two costs will determine whether to replace the defender or allow it to remain in service. If the defender's minimum average is lower, it is economically better to retain it. If the challenger's is lower, the defense by the incumbent machine was unsuccessful and it should be replaced since on the average, the challenger will cost less to own and operate.

In applying the procedure to model the replacement question, Terborgh relied upon two assumptions to rationalize and facilitate the decision process. First, future challengers are assumed to have the same minimum average total costs as the presently available challenger. This assumption takes into account the fact that a decision to replace or not to replace an existing machine at some point in time will affect in a particular way the chain of successive replacements in the future. If a machine is replaced now, future replacements will follow one pattern. If it is replaced after one or more periods, a new challenger may have by then come into being which would head a different succession of future replacements.

Clearly, all future challengers will not exhibit the same minimum average costs, but the assumption that they will is necessary to reduce the model to manageable terms in the absence of perfect knowledge of the future. This assumption gives some acknowledgement to Preinreich's theory of the immediate decision being influenced by future decisions, and also reduces the immediate decision to replace or not to replace to a comparison between the minimum averages of only the defender and the present challenger.

The second assumption Terborgh found necessary concerns the pattern in which a machine accumulates operating and maintenance costs as it ages, given that they rise at some rate over time. Terborgh assumed that a defender machine would accumulate excess operating and maintenance costs relative to the best available replacement at any point in time at a constant rate over its lifetime. He considered these excess costs to represent a machine's "operating inferiority" as compared to the lower costs which would be experienced by that replacement. This constant rate of accumulation could be defined by a rising linear trend which Terborgh termed the "inferiority gradient."

Some studies have concluded that a constant rate of increase for operating and maintenance costs is, in fact, a reasonable assumption, at least when averages for several vehicles of the same type are considered [Ref. 7: pp. 25-26]. Others, such as Russell [Ref. 22: p. 899-911], concede that though a constant rate is a poor descriptor for the actual situation, it is used by default since it is as good as anything else available. In any event, it would appear that Terborgh may have made this assumption for two reasons: as a matter of expediency to allow formulas and shortcuts to replace the tedium of the calculations required to develop the tables shown in the previous chapter, and to provide some forecast of the behavior of future costs. In a later work [Ref. 23: p. 16] Terborgh expanded his original formulas to include two additional patterns of operating and maintenance cost accumulation (rising at an increasing rate and rising at a decreasing rate), giving acknowledgement to the restriction his assumption placed on use of the model.

B. PRACTICAL APPLICATIONS OF THE MODEL

As mentioned previously, a major factor favoring consideration of this model for use by the Navy is that it has found its way into practical applications; again, perhaps because of its simplicity and an ability to be understood by fleet managers. Examples of several of these applications are included in an International City Management Association "Management Information Service Report" [Ref. 24], and will be subsequently summarized. While not employed in a way leading to challenger-defender analyses, the annual average costs provided by the model are used to guide managers toward more economically sound decisions.

The Center for Local Technology, at Oklahoma State University, has developed two forms for use in computing average annual total costs [Ref. 24: pp. 3-7]. One is used to record operating and maintenance expenses, and the other provides a structured format within which those costs and periodic salvage values are used to determine average annual costs. The format is similar to that shown in the tables used to demonstrate the structure of Terborgh's model. However, it includes a proportioning factor which adjusts costs when a vehicle's actual mileage varies from a target per-period average mileage. Discounting of cash flows is not employed; rather, cumulative costs through a period are divided by the number of periods to obtain a simple arithmetic average.

By monitoring the average costs period-by-period, the fleet manager will see when average costs begin to rise (optimal service life has been passed), signaling that it is time to replace the vehicle in question. This application has an obvious disadvantage in that replacement is signaled only after average costs have begun to increase from the minimum, and therefore optimal, average.

This problem may be accommodated by calculating a value which represents a target operation cost for the upcoming period. This procedure is based on the assumption that the average total cost curve takes on a "U" shape (see Figure 3.3) due to a declining then rising trend. After any period through which average total costs have continued to decline, a cost may be calculated for the subsequent period which, if not exceeded, will result in average costs through that period equaling those through the immediate period. As long as next period costs can be anticipated to be below this limit, the average costs will continue the declining trend. Since this would indicate that the period of minimum average cost has yet to be reached, the vehicle should be retained.

Through the use of a series of nomograms, the city of Clearwater, Florida, employs this methodology in managing its fleet [Ref. 24: pp. 5-7]. The nomograms are based on similar ones developed by the Local Government Operational Research Unit, of Great Britain. With them, next-period cost limits reportedly may be determined with relative ease. A separate nomogram has been produced for each of several classes of vehicles, a class being determined by similar patterns of depreciation. Though based on vehicle classes, this method is intended to answer the question of when to replace an individual vehicle.

Similar nomograms have been applied by over 300 local authorities in Great Britain with resultant savings reported to equal 10% of overall expenditures on vehicle purchase, repair and maintenance costs. Several limitations associated with the application of this methodology however must be remembered:

- Use of a vehicle must be approximately the same throughout its life.
- The replacement vehicle must exhibit a similar pattern of costs throughout its life.

- The average cost curve must follow the form assumed (once average total costs begin to increase they will continue to do so).
- Costs for the upcoming period must be capable of being forecasted with reasonable accuracy.

As opposed to concentrating on individual vehicle replacements, the city of Little Rock, Arkansas, uses a group approach to manage vehicle replacements in its fleet [Ref. 24: pp. 7-11]. This procedure requires the period of minimum average total costs to be determined using averaged costs for vehicles of similar expense and usage characteristics, rather than using individual vehicle costs. This information is used by management to determine how many vehicles of a certain class within a fleet to schedule for replacement. For example, if there are thirty vehicles in a class which have (as a group) optimal lives of five years, six vehicles (1/5 of 30) are programmed for replacement each year.

This method of application has provided Little Rock with the benefit of being able to stabilize the number of vehicles which must be budgeted for replacement each year. The city uses life expectancy tables published by the American Public Works Association to determine the replacement period of the various vehicle classes. However, local costs could easily be converted to average periodic costs to determine optimal replacement cycles based on the city's actual conditions.

C. A COMPUTERIZED APPROACH

To combine the management assistance provided by the model with the convenience of data processing technology, a series of five computer programs have been developed by Public Technology, Inc. (PTI), of Washington, D.C., a non-profit public interest organization. Using methodology very similar to that employed by Terborgh, they are designed to calculate minimum average total costs for classes of vehicles based on local cost experience [Ref. 24: pp. 11-13]. Named as a group the Vehicle Replacement Package, these programs guide managers to replace vehicles during the period in which average costs are minimized (point of optimal service life). The package additionally can identify vehicles for particular management attention which incur costs that differ from the class average, and will calculate subsequent period expense limits.

PTI's Executive Summary of this package describes the functions of each program, and provides samples of the management reports generated. It is reproduced in Appendix A. Data for use with the package may come from any record source. However, PTI also offers a computerized information system, the Equipment Management Information System, which may be used to maintain detailed, electronically retrievable vehicle history records.

The ability to apply the model via the electronic medium will of course increase its flexibility and accessibility. However, as with the manual methods previously discussed, its validity will be restricted to the following conditions:

- The vehicles will be used in the same manner over their lifetimes.
- The replacement vehicles will experience costs similar to those replaced.
- Operating and maintenance costs will rise over time and average total costs, once they begin to increase, will continue to do so.

D. INTERACTION OF THEORY AND PRACTICE

The purpose of the model is to develop the replacement decision as an economic decision. The economic life of a vehicle may then be generally thought of as the period during which it is more cost-effective to keep it than to replace it. A consideration of just how that period may be defined will aid in visualizing how the theory and practice interact in implementation of the model.

Peterson [Ref. 25: pp. 366-367] proposes four definitions within the context of which the concept of economic life can be interpreted. Following is a discussion of the applicability of each to the implementation of the average cost model.

> The economic life of a ...[vehicle]...is that period of time over which it has its lowest uniform equivalent cost.

This is the theory behind the approach to using the model employed by the Public Technology, Inc., Vehicle Replacement Package, and the similar, manually applied vehicle replacement systems. The object of this approach is to determine for a vehicle or class of vehicles the optimal service life; this being the period through which periodic average costs are minimized. In using this approach to optimize vehicle operations it is assumed that replacement vehicles will be essentially identical to those replaced and will experience similar costs. This of course does not mean that a vehicle must be replaced by such. It means that this application takes no account of the possibility that a more economical vehicle, or challenger, may be available sooner than the computed service life. This restricts the economics of the question to those which are internal to the system, or are generated solely by the costs of the vehicle or class being examined.

> The economic life is that period of time which will terminate when a new...[vehicle]...promises a lower equivalent annual cost than the cost of keeping the old ...[vehicle]...for an additional year or more.

This more closely describes the basis of Terborgh's application in his use of the model to structure challenger-defender comparisons. Obviously, one would not expect to replace a 1976 vehicle in 1984 with a new 1976 model. Indeed, such a vehicle would not even exist. To then apply the model to derive optimal service lives only as determined by internal economics is to ignore the advantages brought about by advances in technology over time as reflected in lower relative costs. External economies therefore may also influence the replacement decision.

Terborgh accounted for this in defining his concept of operating inferiority as the result of two components [Ref. 17: p. 61]. The first, deterioration, is internally generated through the decline in a vehicle's operating performance as compared with itself at an earlier age. This would be reflected in the increase in operating, maintenance and downtime impact costs theorized to occur as a vehicle ages.

The second component of operating inferiority, obsolescence, is externally generated. It represents the excess costs a new edition of a defender vehicle would experience in comparison with those experienced by the best challenger. A cost such as this would accumulate, for example, as new vehicles are designed for increasingly better fuel economy. It is possible that a highly advanced challenger could cause a defender to become obsolete before it has reached its optimal service life.

Therefore, the concept of economic lifetime may be extended beyond only a simple calculation of the best time to replace a vehicle to minimize its costs. It then becomes a consideration of when to replace as influenced by its own cost experience and the cost experiences of better challengers.

> The economic life is that period of time which will elapse before a ...[vehicle]... will be displaced by another as a result of a future analysis.

The implication of this definition is that regardless of a defender's present age, its economic life begins with the present and continues only until it can no longer defend its position against available challengers. This brings up a particular point regarding the computation of a defender's average periodic costs; that is, that they should be computed without regard to the costs which have been previously incurred.

That this is so is a reflection of past costs being sunk, and having no economic influence on costs which will be incurred in the future. Therefore, the defender side of the challenge becomes an issue of the economics of retaining the existing vehicle for a time beginning with the immediate period. In computing average periodic costs for the defender, the current salvage value is used as the acquisition value and periodic costs from the present onward are input into the model as if they will be incurred beginning in the first period.

This may be visualized by considering a situation where the defender is first sold for its salvage value. The challenge is then a comparison of the choice between purchasing a challenger or buying back the defender for the same price as sold. This conceptually places the two alternatives on the same comparative basis. [Ref. 21: p. 3B-8]

> The economic life is that period of time absorbed by the intended service before the ...[vehicle]... is degraded to another service, or liquidated.

The latter consideration in this definition, liquidation, concerns conditions where an asset will only be required for a finite period, after which it will have no further use. For all intents and purposes, the requirements for vehicles within the Navy may be considered to continue indefinitely, and replacement decisions need not be concerned with this situation.

The consideration of a degraded service assignment defines the concept of economic life as a function of a vehicle's assignment within the organization. This is reflected in the concepts of primary versus secondary replacement [Ref. 17: pp. 24-25]. The former would refer to the procurement of a new vehicle which can economically replace an existing one in the same job. This is the meaning of replacement which to now has been used in this thesis. The latter refers to an asset being replaced from within the organization because it can no longer perform its function as economically as another. It is usually degraded to an assignment of less demanding service.

An obvious example of this occurance within the Navy regards the operation of vehicles in security patrol assignments. In comparison with a sedan assigned to an activity commander, for instance, security vehicles can be expected to reach their optimal service life much sooner since the intensity of use may cause salvage values to decline and operation costs to rise at accelerated rates. Once they have been "run into the ground", they are frequently channelled into a lower mileage assignment, being displaced by a newer vehicle.

Such usage serves to complicate the use of the replacement model to determine optimal service lives in that it results in cost patterns significantly different from the "norm". It is possible that vehicles with similar, though abnormal, rates of usage could be grouped together and modeled as a class to accommodate this problem. However, if the model were to be used for replacement decisions and if it was found to be more economical to replace rather than displace those vehicles. The acquisition system would need to be flexible enough to allow this to be done.

Current DOD policy as implemented in practice has not provided this requisite flexibility. Funding for replacement of underage (though over-mileage) vehicles is frequently not forthcoming, perhaps because the economics of one alternative as opposed to the other cannot now be demonstrated to funding sponsors. Dollar amounts required per vehicle for new acquisition funding are relatively conspicuous in comparison with operating and maintenance funds requirements for an individual vehicle within an existing fleet. Cost conscious managers understandably will tend to defer funding of replacement assets and decide in favor of continuing to operate and maintain existing, though older, assets if the economic consequences of such action are not apparent. An immediate application possibility for the replacement model is therefore suggested by such situations.

Functional displacements of vehicles within the fleet are common occurances since they can be so easily accomplished. Few "switching costs" will be attendant to such a shuffling of assignments except when attached gear (radios, tool boxes, etc.) must be removed and reinstalled. Good management then requires a method by which the problem can economically be accommodated. Appendix B discusses one such method. Developed internally within NAVFACENGCOM, it serves to minimize vehicle operation costs by helping managers put high cost vehicles into low mileage assignments, and vice versa.

V. INPUT DATA: REQUIREMENTS AND AVAILABILITY

In calculating average total costs, certain information is required by the model. Input data will consist of the costs of vehicle ownership and operation. Although some of these costs are common to any application of this type, whether within the public or private sectors, others are unique due to the nature of the vehicle replacement problem from the Navy's perspective.

Previously, it was noted that the literature addressing vehicle or other equipment replacement is consistent in stating that accurate input into a replacement model is necessary to produce valid conclusions. In light of the importance given to data accuracy, this chapter is devoted to a discussion of the input requirements for a model applied to the Navy environment and the present availability of that data.

A. INPUT DATA REQUIRED

The following discussion addresses the types of cost data which would be necessary for model implementation.

1. Capital Costs

- Acquisition: The bulk of this cost will be the purchase price of a new vehicle, to which administrative and other costs incurred as a result of the vehicle's procurement should be added. Examples of these additional costs are costs incurred by the procurement organization as a result of the procurement action, costs of acceptance inspections, transportation costs to the ultimate destination and costs to prepare a vehicle for service (installation of tool boxes or security lights, for example). In short, the total acquisition value consists of all costs which would not otherwise be incurred if a purchase action was not undertaken.

Discussed previously was the need to keep a replacement model simple in order to keep it manageable. A consideration of how to allocate the costs of a purchase organization to one particular action presents an example of how the model can easily become complicated. However, to ignore such costs is to introduce into the model a bias in favor of replacement rather than retention. This provides an example of a situation where, should the costs be of sufficient magnitude to affect the outcome significantly, a manager may be forced into making a simplifying assumption to facilitate manageability of a model (such as procurement costs perhaps representing a percentage of the purchase price).

- Salvage Value: Two cases may be considered regarding the determination of salvage values. One is essentially a "no-salvage" approach whereby initial acquisition costs are simply apportioned over the total period of ownership; the longer the total period considered the smaller the apportionment necessary per period for capital recovery.

In some respects, this in general represents the Navy's situation due to the disposal system under which it operates. When a disposal action is taken against a vehicle, it is transferred to a Defense Property Disposal Office salvage yard where it may be screened in order of precedence by other DOD activities, other Federal agencies, state agencies, and service/educational organizations (such as the Boy Scouts of America). If desired by any one of these organizations, the vehicle is then retransferred to it at no cost. If none desire to requisition it, it is sold at public auction. Frequently, those vehicles passed over during the screening process and eventually sold are in a condition which will justify a price equal only to its scrap value [Ref. 26]. Regardless of whether a vehicle is transferred to another agency or sold at auction, the Navy receives no remuneration (no salvage) from the disposal action.

The result of using a no-salvage approach in accounting for capital costs in the replacement model is that average capital costs will be much greater than those produced by "real life" salvage values, particularly during earlier periods. This is the case since under a no-salvage assumption, the entire value of the asset is absorbed in the periods through which average costs are being calculated, regardless of how few periods are considered (if computing average costs for one period, for example, the entire value of the vehicle is charged to loss of value for that one period). Mathematically, this gives the impression that an asset "depreciates" much more rapidly than it does in reality, causing the average total cost pattern to reach minimum at a point later than it otherwise would based on actual trends. Use of this approach would mean that Navy funds managers would tend to favor continued retention of a vehicle rather than replacement.

An alternative way to view the salvage question is to assign to a vehicle a salvage value equal to the price for which it could be sold on the open market given its age and condition in a particular period. Publications such as the "Kelly Blue Book" or the "N.A.D.A. Official Used Car Guide" would provide guidance for determining these values in the cases of sedans and trucks. While the prices provided by these publications reflect features attributable to market conditions (relative desireability of a particular body style, for instance) which are not directly applicable to the Navy's needs, they also reflect a vehicle's ability to command higher resale values resulting from higher fuel economy or lower maintenance requirements relative to other years and models. In this respect, market-determined salvage values theoretically more closely reflect the retained value of a vehicle as time goes by. While the no-salvage approach is more indicative of the financial aspects of the replacement decision, the imputed salvage value approach is a better indicator of the economic aspects.

The choice of how to account for salvage is not an insignificant consideration. In Klungle's examination of the replacement policies for Navy pickup trucks, the choice caused the determination of optimal service lives to vary from as few as three to as many as seven years depending on the choice of the other variables in the model (longer replacement cycles being associated with the no-salvage case) [Ref. 7: pp. 50-53].

Action is presently underway to revise disposal policies to allow Public Works Centers (PWC's) to sell used vehicles on the open market and apply the proceeds to purchases of replacement assets (this being a reflection of the business orientation of Navy Industrial Fund activities such as PWC's). Here, the market value salvage case is directly applicable. Applying that case in modeling the economics of PWC vehicle replacements and then applying the no-salvage case elsewhere could result in a wide disparity in the ages of vehicles available to PWC-served activities versus activities served by in-house public works departments.

- Interest/Discount Rate: DOD guidance prescribes the use of a discount rate of 10% in performing economic analyses to reflect the premise that public investments should explicitly consider the alternative use of funds they displace or absorb [Ref. 27: Encl (1), p. 6-7]. The use of a discount rate also shows a preference for the timing of cash flows, those being received earlier in the period of analysis being weighted more heavily than those received later.

A discussion of the question of whether or not this is indeed the proper rate to use is beyond the scope of this work. However, it can be noted that use of an incorrect rate may not significantly affect the outcome of the replacement model. Kiesling [Ref. 15: p. 37], for example, found that variations of at least five percent will be insignificant, and Klungle [Ref. 7: p. 52], concluded that a similar variation changed only slightly the determination of the optimal service life for pickup trucks. The actual impact of the discount rate will depend on the relative magnitude of ownership and operation costs; relatively higher ownership costs causing the minimum average total cost to occur in a more distant period.

2. Operating and Maintenance Costs.

It is within this category that costs which result from operating a vehicle (fuel, oil, lubricants, etc.) are incurred. Also, maintenance, repairs, and other costs necessary to support those operations are included. In applying the model, it is necessary to include only costs which vary over time or with the choice of a particular vehicle. Costs which do not change with these variables, which are essentially fixed, are not relevant to the decisions which are based on the use of the model.

The differences in costs which occur over time are due to deterioration, which is chargeable to a vehicle in comparison with its "earlier self." Differences due to choice are reflected in obsolescence, chargeable to a vehicle as compared to a more economical replacement. A difference in costs which would be fixed for one or both of the alternatives in a challenger-defender analysis, but at different levels, is also relevant. An example of such a cost would be special tools which would be required to maintain a potential challenger. [Ref. 28: p. 482]

In calculating the optimal service life of a particular vehicle, only deterioration (the amount each period by which a vehicle becomes inferior to a new replica of itself) is applicable. The objective of the service life calculation is to determine when decreasing costs of ownership are offset by increasing costs of operation. Terborgh used the convention when determining the service life of challenger vehicles of setting the value of his inferiority gradient (essentially, a measure of operation costs) to zero for the first period since a vehicle is not inferior to itself when new. Subsequent periods were then incremented to reflect the amount by which operating and maintenance would increase with age [Ref. 17: pp. 76-77]. In the case of a challenger-defender comparison, the defender vehicle must be charged with both deterioration and obsolescence costs to reflect the amounts by which it is inferior to the potential replacement.

In the practical application of the replacement model for decision-making, the separation of fixed costs from varying costs is actually not a necessity, simplifying the processes of determining values for input data. This is true since even though only varying costs influence the decisions based on the model, the inclusion of fixed costs will not cause those decisions to change.

To illustrate this, Table VII manipulates the hypothetical data used to develop the tables in Chapter III. Other than values for operating and maintenance costs which are shown in Table VII, all other input data remain unchanged. The first two columns in the table repeat the original values for the operating and maintenance costs and the annual average total costs. The second two columns parallel the first two except that for illustration, Terborgh's convention of setting first period costs to zero has been employed (each period decremented by the amount of first period costs). The third and fourth of the two-column sets are similar to the previous two except that values of $ 5,000 and $ 15,000 have been added respectively in each period to represent two possible levels of fixed operating and maintenance costs.

Notice that in every case, the decisions which would result from applying the replacement model would be the same. The optimal service life is in all cases six years. The average cost per year of retaining a vehicle for ten years, for example rather than replacing it at the six year point (difference between average total costs of sixth and tenth years in each case) is always $184. The result of adding fixed operating and maintenance costs is merely that the total average annual costs in each period are increased consistently by that amount.

How does this simplify the practical application of the model? Considering for instance the fuel costs of operating a vehicle, deterioration would be represented by an increase in these expenses (assuming constant usage and fuel prices) as a vehicle aged and the engine became more inefficient. Obsolescence would be reflected by the savings in fuel expenses which could result from operating a challenger designed for increased fuel economy relative to the the fuel consumption of the existing vehicle. Due to the fact that the nonvarying component of fuel expenses (reflected in neither deterioration nor obsolescence) will not affect the final decision if included in the model, the model user is spared the chore of separating it out from those components which represent deterioration and obsolescence.

TABLE VII

EFFECT OF FIXED COSTS ON O&M INPUT

	ORIGINAL O&M INPUT DATA		FIRST PERIOD O&M SET TO ZERO		WITH $5,000 FIXED COSTS		WITH $15,000 FIXED COSTS	
PER	O&M	AAT	O&M	AAT	O&M	AAT	O&M	AAT
1	750	4,250	0	3,500	5,000	8,500	15,000	18,500
2	1,119	4,009	369	3,259	5,369	8,259	15,369	18,259
3	1,774	3,928	1,024	3,178	6,024	8,178	16,024	18,178
4	2,003	3,832	1,253	3,082	6,253	8,082	16,253	18,082
5	2,589	3,810	1,839	3,060	6,839	8,060	16,839	18,060
6	2,947	3,806	2,197	3,056	7,197	8,056	17,197	18,056
7	3,412	3,830	2,662	3,080	7,662	8,080	17,662	18,080
8	3,878	3,875	3,128	3,125	8,128	8,125	18,128	18,125
9	4,223	3,926	3,473	3,176	8,473	8,176	18,473	18,176
10	4,657	3,989	3,907	3,239	8,907	8,239	18,907	18,239
11	4,998	4,053	4,248	3,303	9,248	8,303	19,248	18,303
12	5,411	4,124	4,661	3,374	9,661	8,374	19,661	18,374

O&M= Operating and Maintenance Costs per Period
AAT= Average Annual Total Costs (derived using hypothetical cost data from Appendix A except that Operating and Maintenance costs are altered to demonstrate the effects of including fixed costs)

Another consideration with respect to operating and maintenance costs is how to accommodate capital additions or improvements. An example of a capital addition could be the installation of a retrofit air conditioner in a sedan, given that it would not be removed prior to disposal and its installation increases the value of the asset. Major overhauls such as engine replacements (a capital improvement), unlike "routine" maintenance and repairs which tend more toward preserving a vehicle at approximately its present condition, return it to a previous (more valuable) condition.

Costs of capital additions/improvements are addressed at this particular point since they may be included within the model as if they were normal costs of a vehicle's operation. Though they could be included as a capital cost, it is conceptually perhaps more logical to group them as an operation cost since they probably will be incurred in the same facilities and by the same personnel as routine maintenance and repairs. Also, including them as if they were operating and maintenance costs will simplify the process of maintaining cost records necessary to provide input data.

Within the replacement model, the difference between computing capital addition/improvement costs as capital costs or as operating and maintenance costs is that the former case will result in average periodic capital costs will decline at a slower rate while in the latter, average periodic operating and maintenance costs will rise at a more rapid rate. Either way, there is no difference in the values computed for average total costs. The choice as to how capital addition and improvement costs are categorized within the model then is not of any computational significance. What is of importance is that salvage values must be adjusted by the amounts by which they are increased as a result of the addition or improvement, and this will affect the final computation of average total costs.

3. Downtime

Some studies have approached the problem of downtime from the converse perspective, choosing rather to determine effectiveness (the time a vehicle is "up"). Effectiveness has been defined as having elements of availability and reliability; availability being the probability an equipment asset will be available for a mission when needed, and reliability being the probability it will complete a mission once begun. [Ref. 29: pp. 11-13 and Ref. 30: pp. 82-84]

As discussed in a previous chapter, the data requirements for a probabilistic approach to vehicle replacement would be more rigorous than a deterministic one. Given that data in the detail necessary for development of availability and reliability estimates of vehicle types may not be practically available, costs associated with vehicle downtime are then best related to availability [Ref. 10: p. 9]. By determining the time in which a vehicle is unavailable for use (in the shop for repairs), a penalty can be assessed against it as a cost of operation.

This penalty cost should be in dollar terms to provide commensurablity with other model inputs. It can be the rental cost of another vehicle to replace the vehicle that is down or if a rental replacement is not feasible, it should be a function of the cost of impact on the activity's mission from the vehicle not being able to carry out the purpose for which it is intended. These impact costs reflect time lost by personnel who would have had a need for the vehicle and costs resulting from the personnel not being capable of carrying out the tasks for which the vehicle was needed. Little thought concerning this subject is needed to visualize situations in which impact costs could be incurred in almost infinite combinations due to "ripple effects". Determining the value of these costs would obviously be a highly subjective exercise.

However, to ignore these costs in the replacement decision is tantamount to denying their existence altogether, and they are as legitimate to the economics of the replacement model as are the direct labor costs of maintenance mechanics. However, they are so difficult to determine that they are frequently "assumed away", resulting in an unjustified bias being introduced into the model toward retention.

Since the model deals exclusively in terms of dollars, it requires that a dollar value be assigned to take downtime costs into account, whether determined by the costs of a replacement vehicle, as a proportion of repair costs as suggested by Russell [Ref. 22: p. 903], or as an amount directly related to the degradation of an activity's ability to carry out its mission.

It may be asked of those who would object to an accounting for these costs because the subjectivity of the situation can easily lead to an incorrect determination, will the inclusion of no costs be any less incorrect? It is reasonable to believe that neither will reflect the true value of impact costs experienced by the activity, but the resolution of this problem rests not on whether or not to include these costs, but on the degree to which they can be accurately assessed.

The illustration of the conversion of periodic costs into average costs in Chapter III did not, for the sake of simplicity, include downtime costs. Introducing them would be simply a matter of adding them to the model in the same fashion as the operating and maintenance costs.

The analyses of vehicle operation histories led Streilein to the conclusion that downtime rates would not vary with a vehicle's age [Ref. 11: p. 20] (though he cautioned that an increase could occur). Klungle's data led to an opposing conclusion; that a definite increase occurred for Navy pickup trucks at an almost constant rate as they age [Ref. 7: p. 26-30]. Though supporting data were not included, other literature sources addressing the subject which were examined during the research of this thesis were all but unanimous proponents of the increasing trend. Deferring to the preponderance of opinions supporting the increasing trend, the influence of costs resulting from downtime impact must be considered since they will affect the model in a way similar to that caused by deterioration.

4. Disposal Costs

Just as costs incurred as a result of a vehicle's acquisition are valid to the replacement model, so, too, are costs which occur when that vehicle must be disposed. Examples would include administrative and transportation expenses, and costs to prepare it for disposal (remove radios, security vehicle lights, etc.).

Should Public Works Centers eventually be allowed to sell used vehicles on the open market, attention would need to be given to how best to present the vehicles for sale. Higher prices may be paid for vehicles which have been "fixed up", but managers must evaluate cost trade-offs to ascertain that special preparation expenses will be returned in the form of a sufficiently higher price.

5. Productivity Costs

It may be noted that throughout this thesis the implication has been that the vehicles to which the replacement model will be applied can be compared only with respect to costs; that there is no input component which accounts for benefits received as a result of productivity differences between two vehicles. Particularly with respect to administrative use vehicles (cars, pickup trucks, busses, etc.) none is required since the product of their operation (transportation of personnel and material) will be essentially equivalent regardless of the choice or age of the vehicle. Therefore, consideration need only be given to differences in costs between two alternatives necessary to obtain these equivalent products.

Some CESE assets, however, are of such a nature that a difference is discernable between various choices in both costs and output. Equipment within this category would include such assets as construction and weight handling equipment. The replacement model is capable of being extended to cover this situation. This could be accomplished by making some accounting for productivity obsolescence in the form of a charge to operating costs. It would require a value to be on the improved production which could be gained from a potential replacement, and applying it as a penalty cost against the existing defender. Increased productivity cannot ordinarily be measured in revenue terms within the Navy's environment as it may in the commercial world. However, its influence nevertheless is valid to the replacement question; its effect being somewhat similar to obtaining an equivalent level of productivity at a lower cost.

B. EXISTING DATA BASE

Now that the input requirements for the model have been identified, the composition and structure of the data base which presently exists for Navy vehicles will be undertaken.

A registration number, generally referred to as a "USN" number, is assigned and affixed to each vehicle at the time of its acquisition by the Navy to establish and maintain permanent and positive identification of that vehicle during its lifetime. Additionally, an individual equipment history record file is established for each vehicle and is required to be maintained in a complete and up-to-date status by the vehicle holder from the time the vehicle is acquired until it is transferred for disposal or excess. History record files accompany vehicles transferred from one activity to another and contain as a minimum the following: (1) original receipt documents, which normally include the acquisition cost and contract number under which the vehicle was procured; (2) technical identification and specification data; (3) Shop Repair Orders (SRO's) covering all inspection, maintenance, and repair items accomplished to date; (4) accident reports; and (5) other appropriate documentation considered necessary for further reference purposes, such as warranty work and unsatisfactory equipment reports [Ref. 5: p. 17-13].

The SRO is utilized to authorize, control, and account for labor and material expenditures for each instance of maintenance, repair, modernization, alteration, or improvement of an item of equipment. Examination of the information recorded on each SRO provides a manager with the ability to determine the dates the vehicle entered and left the shop, compute the amount of time the vehicle spent in the shop (downtime), identify what type of work was performed (maintenance, repair, or other), identify the costs of that work as segregated by labor and material charges, and note the accumulated mileage incurred by the vehicle at the time of work performance. Although this information is available from the individual SRO's, the structure of current management information systems employed does not allow the extraction of data in the required format (annual maintenance and repair costs, fuel costs, and accumulated mileage for each year of the vehicle's life) necessary for the computation of the average annual cost required to be utilized by the model.

Vehicles are generally either assigned to appropriated fund activities who perform in-house maintenance and repairs for that activity, or to centralized Public Works Centers, Navy Industrial Fund activities that fulfill transportation requirements and perform vehicular maintenance and repairs on a reimburseable basis for the appropriated fund activities in their vicinity. Each has its own management information system as discussed below to satisfy its respective needs.

1. Public Works Departments

Public Works Departments provide in-house maintenance and repair services for vehicles assigned against their activity's allowance. The formal information system utilized by transportation managers is comprised of the NAVCOMPT Form 2168, Operating Budget/Expense Report and the NAVCOMPT Form 2169, Performance Statement. These reports are produced monthly by the standard activity accounting system utilizing the SRO costing data and records of fuel issues, and are provided by the activity Comptroller/Fiscal Officer.

The Operating Budget/Expense Report provides accrued expenses, accumulated for the year to date by Equipment Cost Code (ECC), (a four digit numerical code utilized by NAVFACENGCOM to distinctly differentiate types of equipment by function and capability: i.e. ECC 0313 describes a two wheel drive 1/2 ton pickup truck whereas ECC 0316 describes a four wheel drive 1/2 ton pickup truck), and summarized by budget cost account line item. The Performance Statement provides actual fiscal year to date totals for accrued expenses for each cost account line item and the percentage of its budget amount. Although cumulative costs for each year are available by ECC, the level of detail required for use in the proposed model is by individual USN numbered vehicle.

Extensive manipulation of the maintenance and repair costing data contained in the SRO's would be required in order to provide cumulative costs for each year of each vehicle's life. Additionally, determinations of mileage accumulated per year by each vehicle are difficult to accurately access solely from SRO data due to the relative infrequency of maintenance and repair requirements. Although accurate current year mileage information by USN number may be extracted from the fuel issue records, activities normally only retain the current backup data used as input to that year's activity accounting system. Upon commencement of a new year, the source data is discarded, and only the activity accounting system output is retained as a permanent record of expenses.

2. Public Works Centers

Public Works Centers, due to their nature as Navy Industrial Fund activities operating in a business-like environment where costs and revenue must be continually monitored, have established a highly computerized management system. The information and procedures necessary to perform the functions of this management system are published in five volumes of a NAVFACENGCOM publication, one of which addresses transportation management [Ref. 31]. This area is further divided into four subsystems: Transportation Maintenance Production, Transportation Maintenance, Transportation Operations, and Transportation Cost Reporting.

The basis for vehicle maintenance and repair cost data is again individual SRO's, with fuel consumption also input into the system. Utilizing a combination of established monthly reports, all of the data elements required for the proposed model are accumulated and presented by the periods month-to-date, quarter-to-date, current year-to-date, and inception-to-date. Although detailed by USN number, the system does not have the ability to retain the data as accumulated for each year of a vehicle's age. Once a current year elapses, a new current year's file is established. The inception-to-date file is the only record of past costs incurred that currently is kept. Costs for each year of a vehicle's life could be maintained by retaining a hard copy or electronic record of the required reports at year end, but this has not historically been accomplished and therefore, such data are not presently available.

VI. NAVY APPLICATIONS OF THE MODEL

In previous chapters, a model considered to be suitable for practical application within the Navy has been identified and described. Theoretical and actual applications have been discussed, and consideration in some detail has been given to the input required to exercise the model properly. This chapter addresses specific applications in which it is thought the model can be used within the Navy's vehicle management environment.

A. FLEET WIDE REPLACEMENT POLICY

One apparent use of the model is as a means to determine the optimal service lives of various vehicle types within the Navy's fleet. The result of such an application would be an updating of the age criterion used to signal the time for a vehicle's replacement.

That, of course, was the objective of the empirical studies discussed in an earlier chapter. In order for service lives to be redetermined, the steps followed in several of those studies would be retraced using current cost data. In general, the procedure would be as follows:

- Cost data for the required model inputs, for whichever vehicle type is being considered, would have to be collected centrally. A sufficiently wide sampling would be required to prevent any bias due to regional influences from being introduced.
- The data would be combined to determine the mean periodic costs of that vehicle type Navy wide. Particular attention in this regard would be necessary to accurately portray operating and maintenance costs for older vehicles.

It is widely held that operation costs will continue to increase under normal conditions and signal a definite replacement point. Three reasons are given to explain why some DOD data (the previously cited DARCOM study, for example) have occasionally indicated otherwise: (1) as a vehicle gets older and more costly to operate, it is frequently relegated to a lower-use assignment where it will have fewer opportunities to accumulate costs; (2) one-time repair limits artificially hold down repair costs for older vehicles and (3) required maintenance as a vehicle approaches its replacement age is simply deferred indefinitely. One GAO report cited the results when one service, faced with extreme limitations on vehicle procurement funding, liberally waived the one-time repair limits. Maintenance and repair costs rose dramatically, in some cases exceeding the price of a new vehicle.

The possibility of other than a continually rising trend would therefore appear to result from replacement policies rather than the true economics of the replacement question. The effects of these policies should be exorcised before the input of operation costs into the model if the correct decisions are to be derived therefrom. The DARCOM study accomplished for this by determining a regression equation using the cost data from earlier years which defined operation costs as a function of time. By using this equation, a continually rising trend was extended through the later years which was believed to represent the form costs would take if not constrained by external policies. This seems to be a reasonable approach to the problem, and would appear to be a way in which "mean" values for Navy operation cost data could be determined for use with the model. A similar technique would be necessary to accurately reflect downtime, which would also be influenced by management policies (for instance, an older vehicle in a low-use assignment would have less chance to "go down" than if subjected to normal use).

- Once fleet-wide mean costs have been determined, revised optimal service lives could be determined for Navy vehicles which would be based on more current cost experiences.

The use of mean costs to determine replacement ages does have a drawback. Although it will result in the determination of a fleet wide average service life for a particular vehicle type, management of individual vehicles will not be optimized by adherence to this average life with no regard for unique conditions. Navy wide cost experiences are influenced by wide ranges of geographic and climatic environments, local wage conditions and maintenance procedures, and mission requirements. Inherent differences between two separate vehicles also influence costs significantly. Use of a fleet-wide average life to replace individual vehicles will result in some being replaced prior to their optimal lives, and some later.

In San Francisco, California, for example, vehicles are subjected to a coastal environment; hilly terrain; and heavy, stop and go traffic. Wage rates for the area are extremely high relative to many parts of the country. Obviously the costs of a vehicle's operation in San Francisco should have no influence on individual vehicle replacement decisions at an activity located in a more rural setting, where vehicles operate on flat roads and in less intense traffic, and wage rates for maintenance mechanics may be much lower.

It must be conceded, however, that mean value targets do have their place. The Navy centrally manages the procurement of all CESE assets. In Fiscal Year 83, the Navy's budget submission for automotive vehicles amounted to some $ 25 million for 1,826 various equipment items. The DOD budgeting system is such that it required estimates for this submission to begin years earlier.

When considering the requirement to forecast and program vehicle replacements on a scale of this magnitude, it becomes apparent that practicality forces the use of mean values to introduce manageability into the system. Within this context, the replacement model may be used to determine, based on the economics existing in the recent past, the average number of vehicles in the fleet which will reach their optimal service lives at various times in the future. With this information, programmers may become better equipped for forecasting procurement numbers for upcoming years.

B. INDIVIDUAL VEHICLE REPLACEMENTS

The application to which the model seems most adaptable and in which it is believed to offer the most tangible benefits, though, is at the field level; in the hands of the activity transportation manager. Regardless of the policies established and actions taken at NAVFACENGCOM and other headquarters levels, it is his actions which will ultimately determine the success of the Navy in managing its transportation assets, meeting mission requirements while optimizing the economics of vehicle ownership and operation. Mean values for Navy-wide cost data used to determine fleet service lives are, in the final analysis, very much a function of how well each individual asset has been managed.

The model's value as an activity-level manager's tool would not merely be restricted to aiding replacement decisions. Since it structures in a comprehensible form the results of all actions which influence the costs of owning and operating a vehicle (or group of vehicles), it reflects the effects of all management policies. As much value as it may have in making choices in the present or in forecasting the future, more may be found in its ability to show the real economic outcome of the past. By having at their disposal a means to view the product of past policies, fleet managers can be better equipped to know how to direct policies of the future.

For an example, return to the problem cited in an earlier chapter of how to manage security vehicles, usage of which far exceeds that of vehicles in most assignments. The DOD mileage criterion (72,000 for sedans and light trucks) may be exceeded within just a few years, yet activities are frequently faced with sponsors who rely mostly on the age criterion (six years) to signal replacement eligibility. As a result, activities must retain vehicles throughout their full chronological lives as determined by the age criterion, even though the vehicle may be driven many more miles than the mileage criterion requires. The question then arises: would it be more cost effective to place a new vehicle in the high mileage assignment initially then later, when it may be more prone to require maintenance actions, relegate it to a lower mileage assignment; or would it be more economical to follow an opposite course and provide in high-mileage assignments a vehicle which is older, but in good condition? By being able, through use of the model, to examine the effects of having followed different alternatives in the past, better decisions regarding questions such as these can be made in the future.

The case for suggesting, at this time, the use of the model as an activity-level tool is enhanced by a fortuitous circumstance of timing. Appendix C describes Project BEST, the computerized management system presently being implemented for activity public works departments. With the transportation management software module, technology needed to electronically store and retrieve the cost data necessary to effect the model's use in a dynamic setting will soon be put into place at many activities. The software necessary to interface with the existing system and assemble the data in the form necessary for the model could possibility be included as an extension to this initiative.

For the activity-level transportation manager, the model could provide the following benefits.

- The results of all management actions which affect costs could be structured in an understandable and comparable form.
- Optimal service lives could be forecasted for the future, at least as accurately as cost estimates will allow, and could be determined in retrospect to see if proper decisions have been made in the past.
- Expense targets for upcoming periods could be calculated. Management's assessments of the possibility of meeting a target, expressed as a range above and below, would be shown as an economic consequence.
- Cost trade-offs between continued retention of older vehicles and procurement of new ones could be demonstrated to the TEMC's.

VII. SUMMARY & CONCLUSIONS

A. SUMMARY

In Chapter I of this thesis, the requirement for an alternative to the currently-specified DOD vehicle replacement criteria was identified. Chapter II discussed the origin of these 20+ year old criteria, and looked briefly at the development of equipment replacement theory. This chapter also highlighted several empirical studies that question the validity of the DOD criteria.

In Chapter III, the results of those studies were used to establish a case against the application of any criteria which remain unchanged, regardless of changes which may occur over time in the economics of the replacement decision. A case was also made against applying identical criteria service wide, with no accounting for variations between the services. An economic model was then identified and proposed as a means to structure the replacement decision in dynamic practical applications.

Chapter IV examined uses for the model proposed in theory, and uses to which it has actually been placed in practical applications. Chapter V described the input data which would be required for the model to be used to guide Navy vehicle replacement decisions, and the current availability of that data.

In Chapter VI, the model was suggested as an aid for vehicle replacement programming due to its ability to determine optimal replacement cycles. Also suggested, in conjunction with the Project BEST computerized transportation management system, was its use as a tool to assist activity vehicle fleet managers in achieving the cost effective management of individual vehicles.

E. CONCLUSIONS AND RECOMMENDATIONS

This thesis has not concluded that replacement decisions based on age are inappropriate in and of themselves. Indeed, it has proposed a model for structuring replacement decisions based on the effects of various expenses a vehicle will incur as it ages. What it has concluded is that incorrect decisions will result from the application of age criteria which give no account to the changing economics of the replacement decision, or which do not account for all influencing costs. The proposed model was selected because it was theoretically sound, yet simple enough to lend itself to both fleet wide replacement programming and the management of individual vehicles. Applied in a dynamic setting, it will result in criteria which will change as appropriate to the ever-evolving economics of the replacement question.

This thesis also presents the opinion that a method of managing the replacement of individual vehicles at the activity level, which the model facilitates, promises to provide a more cost effective basis on which to make replacement decisions. Once activities are given the capability to structure vehicle cost data in a way which facilitates examination and comparison, information regarding the economic consequences of management decisions and policies will be available. Presentation of that information to TEMC's and cognizant OPNAV sponsors will help convey to them the economic impact of replacement versus retention decisions.

The current stumbling block to immediate implementation of this process is the format of the available cost data. An essential key to the successful use of this model is the accurate recording of cost data on an individual vehicle basis for each year of life. Because it may not be possible for activities to recover past costs for input into the model, use of the model may hold more promise for structuring the replacement decisions of the future than for those of the present. The integration of the replacement model with the electronic record keeping capabilities of Project BEST promises to provide a viable means by which the model may be implemented.

APPENDIX A

PUBLIC TECHNOLOGY, INCORPORATED VEHICLE REPLACEMENT PACKAGE

Introduction

The purchase of a new municipal vehicle by a department is a highly visible expenditure usually involving a budgetary appropriation by the city council. The department's expenditures to operate and maintain its existing vehicle fleet are less visible, if not invisible, being part of its day-to-day operating expenses. A council that seeks value for its money should regard both kinds of expenditures as equally important for both contribute to the total cost of the vehicle fleet. Action to reduce one kind of expenditure, often leads to an increase in the other. Deferring a purchase for too long can lead to increases in operating and maintenance costs just as attempts to reduce these costs by premature purchases can lead to high procurement costs.

What is needed is an accurate and easily understood method for indicating when a vehicle should be replaced. This method will show, on a regular basis, whether replacement or retention is recommended, what cost penalties the city will incur if it retains a vehicle that ought to be replaced or replaces a vehicle that ought to have been retained. The first of the above requirements allows the line official, say the Director of Public Works, to make a concrete recommendation. The second allows the council to decide whether it can justify a capital expenditure in the current budget.

What is the Problem?

Each year at budget time, vehicle fleet managers review their need for new vehicles and find they must decide, for each of their vehicles, whether to:

- buy a new vehicle of similar capability to replace it, or to
- make do with the old vehicle for another year.

To come to a reasoned decision an administrator must have a means of comparing the cost he will incur by keeping the vehicle another year to the cost of buying a new vehicle and operating it for the same period of time. His basic comparison is between two future costs. He wants to take the course of action that will minimize his future costs. The vehicle replacement model will help him determine his course of action.

Vehicle replacement decisions are based on a shift in vehicle-ownership costs with the passage of time. In the early years of ownership, these costs are dominated by the declining resale value of the vehicle. In later years, this decline levels off and is obscured by rising operating and maintenance costs.

What is a Vehicle Replacement Model?

It is a systematic method for:

- Recording relevant past costs due to operation, maintenance and decline in market value of vehicles
- Estimating typical costs of keeping and of replacing each vehicle
- Comparing vehicle performance against norms to detect exceptions.

What Does the Model Do?

- It uses vehicle information grouped in functional vehicle classes
- It summarizes past costs into patterns to give economic lifetimes for each class of vehicle
- For a specified vehicle, it calculates
    - its anticipated economic lifetime compared to that of the average vehicle in its class
    - its maximum repair limit-- the amount of money it is worth spending on a one-time repair when the resale value of the unrepaired vehicle is known
- It provides the decision-maker with information needed to set and administer policies.

- It will not make the final decision of keep vs. replace.
- It will only measure and indicate; it will not interpret measurements and take action.

A model is a diagnostic tool. It is not bound by the constraints that bind the administration. For this reason, a model's recommendations should be subjected to the manager's interpretation and judgment. For example, a model will often indicate to a manager that it would cost the city an additional sum of money to keep a vehicle rather than replace it. It would be up to the manager to decide whether this sum is large enough to justify an appropriation request for replacement.

How Does the Model Work?

The PTI Vehicle Replacement Package consists of five computer programs and associated documentation: (1) a curve-fitting program, (2) an economic-lifetime program, (3) an expense-trend comparison program, (4) a repair-limits program, and (5) a depreciation curve estimation program.

- The curve-fitting program (CURVEFIT) combines cost data on similar equipment to determine patterns in operating and maintenance expense. These patterns are updated periodically with the most current figures available.
- The economic lifetimes program (LIFETIME) combines expense patterns with effective cost due to loss in resale value (depreciation), to determine the point in the equipment life cycle where rising operation costs overshadow the loss in value. This length of life is recommended as a replacement policy, since it gives a minimum average cost per period (MACP), usually expressed as minimum average annual cost. A shorter life cycle costs more on the average due to replacement purchase costs, whereas a longer cycle costs more due to rising maintenance cost.
- The trends comparison program (TRENDS) identifies upcoming replacements and those vehicles which are costing appreciably more or less than the average.

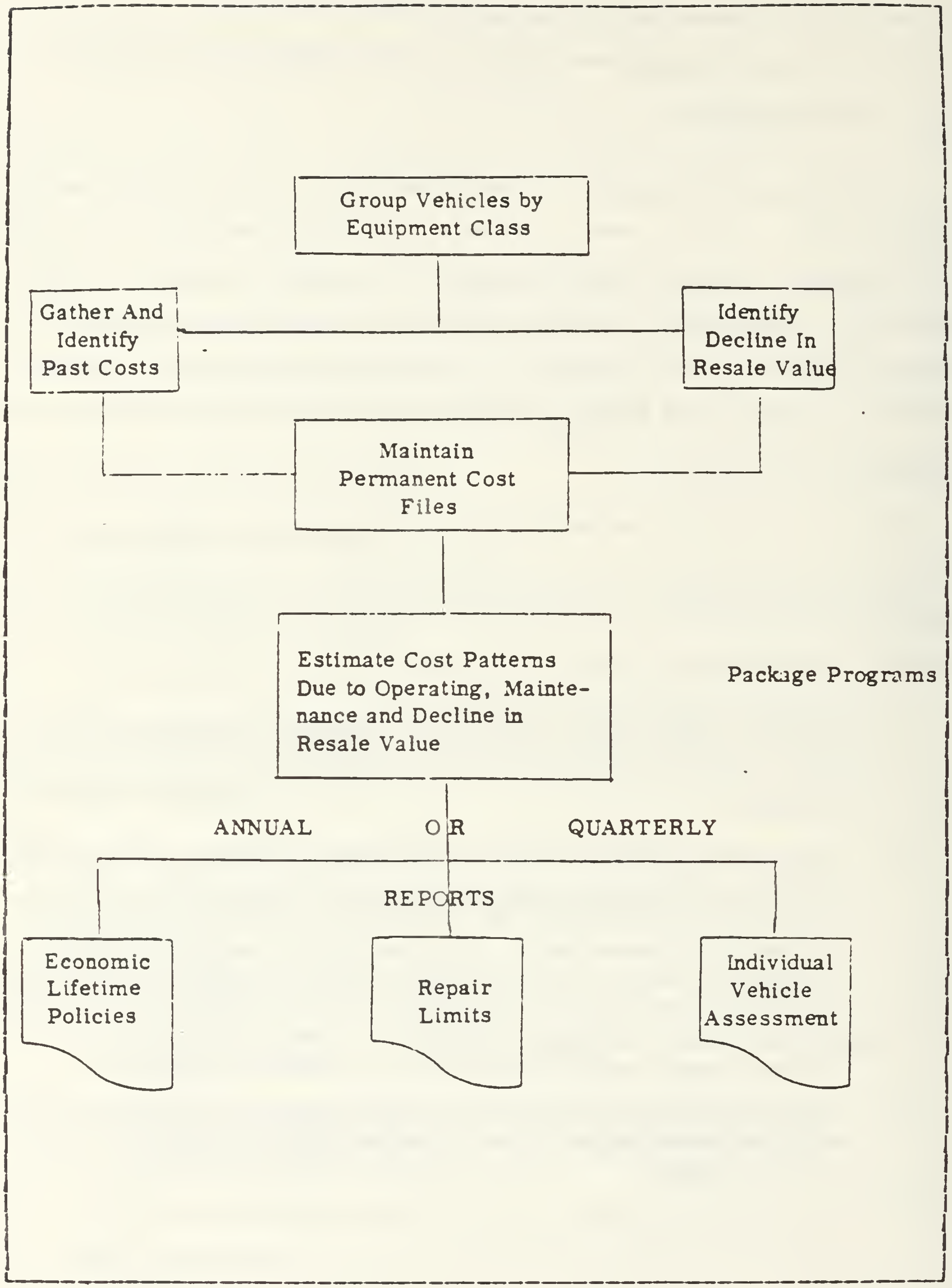

Group Vehicles by Equipment Class
Gather And Identify Past Costs
Identify Decline In Resale Value
Maintain Permanent Cost Files
Estimate Cost Patterns Due to Operating, Maintenance and Decline in Resale Value
Package Programs
ANNUAL OR QUARTERLY
REPORTS
Economic Lifetime Policies
Repair Limits
Individual Vehicle Assessment

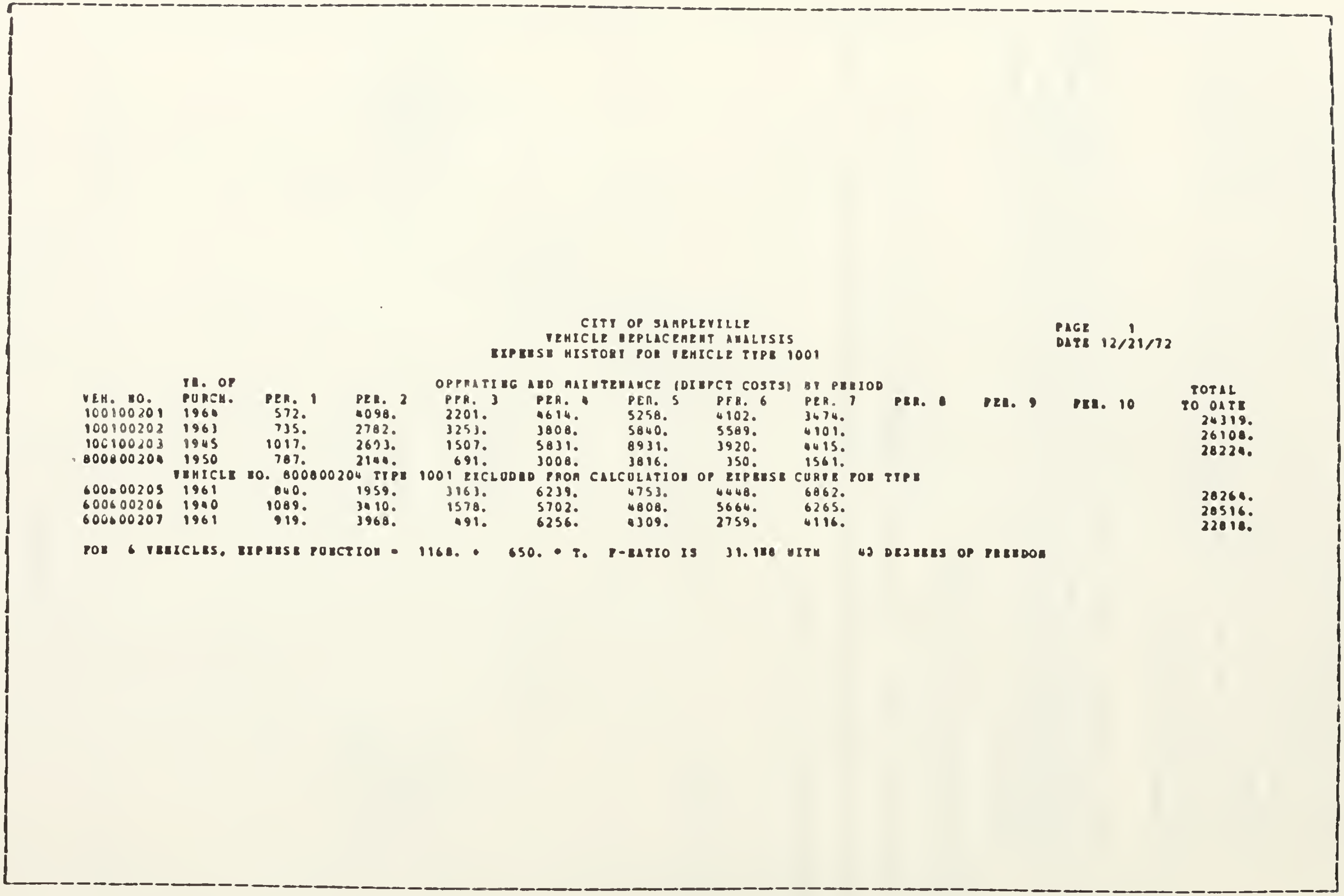
Figure A.1 PTI Information Flow.

- The repair limits program (REPAIRLM) produces tables of economic repair limits giving rules of thumb for repair vs. replace decisions. A very real dilemma arises when an older vehicle comes up for an unexpected repair. Does its limited remaining life justify the cost of the repair, or is the city better off getting rid of the unrepaired vehicle and buying a new one? If an upcoming repair will cost more than the corresponding limit value, a city is better off selling the vehicle in its unrepaired condition.

- The depreciation curve program (DPRCURVE) shows the patterns of declining resale values indicated by actual experience. These patterns, again by vehicle type, are used to establish the net cost due to lost value for each possible replacement cycle in the LIFETIME Program.

What do these Reports Look Like?

The following figures show sample outputs for a single class of vehicles. The data represents actual values for a medium-sized eastern city, for a group of seven vehicles in similar use.

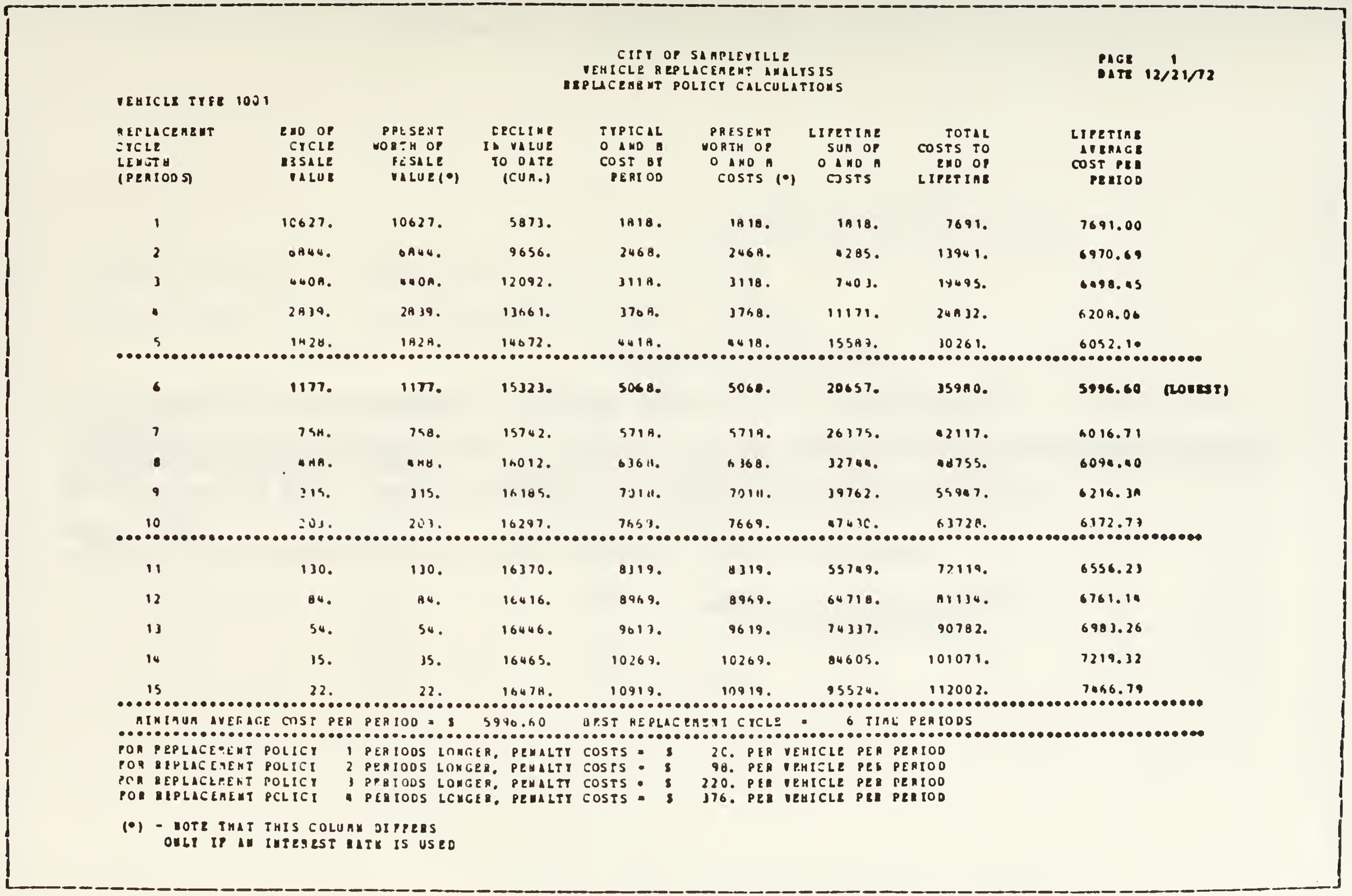


```
                                               CITY OF SAMPLEVILLE                                    PAGE    1
                                           VEHICLE REPLACEMENT ANALYSIS                               DATE 12/21/72
                                       EXPENSE HISTORY FOR VEHICLE TYPE 1001

              YR. OF                          OPERATING AND MAINTENANCE (DIRECT COSTS) BY PERIOD                       TOTAL
VEH. NO.      PURCH.    PER. 1    PER. 2    PER. 3    PER. 4    PER. 5    PER. 6    PER. 7    PER. 8    PER. 9    PER. 10    TO DATE
100100201     1964        572.     4098.     2201.     4614.     5258.     4102.     3474.                                     24319.
100100202     1963        735.     2782.     3253.     3808.     5840.     5589.     4101.                                     26108.
100100203     1945       1017.     2693.     1507.     5831.     8931.     3920.     4415.                                     28224.
800800204     1950        787.     2144.      691.     3008.     3816.      350.     1561.
             VEHICLE NO. 800800204 TYPE 1001 EXCLUDED FROM CALCULATION OF EXPENSE CURVE FOR TYPE
600600205     1961        840.     1959.     3163.     6239.     4753.     4448.     6862.                                     28264.
600600206     1940       1089.     3410.     1578.     5702.     4808.     5664.     6265.                                     28516.
600600207     1961        919.     3968.      491.     6256.     4309.     2759.     4116.                                     22818.

FOR  6 VEHICLES, EXPENSE FUNCTION =  1168. +   650. * T.  F-RATIO IS   31.188 WITH    43 DEGREES OF FREEDOM
```

Figure A.2 CURVEFIT Program Output.



```
                                              CITY OF SAMPLEVILLE                                  PAGE    1
                                         VEHICLE REPLACEMENT ANALYSIS                              DATE 12/21/72
                                        REPLACEMENT POLICY CALCULATIONS
VEHICLE TYPE 1001

REPLACEMENT      END OF     PRESENT    DECLINE     TYPICAL    PRESENT   LIFETIME     TOTAL          LIFETIME
CYCLE             CYCLE    WORTH OF   IN VALUE    O AND M    WORTH OF    SUM OF    COSTS TO         AVERAGE
LENGTH           RESALE      RESALE    TO DATE    COST BY     O AND M   O AND M     END OF          COST PER
(PERIODS)         VALUE    VALUE(*)     (CUM.)     PERIOD   COSTS (*)     COSTS   LIFETIME            PERIOD

    1            10627.      10627.      5873.      1818.       1818.     1818.      7691.           7691.00
    2             6844.       6844.      9656.      2468.       2468.     4285.     13941.           6970.69
    3             4408.       4408.     12092.      3118.       3118.     7403.     19495.           6498.45
    4             2839.       2839.     13661.      3768.       3768.    11171.     24832.           6208.06
    5             1828.       1828.     14672.      4418.       4418.    15583.     30261.           6052.14
••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
    6             1177.       1177.     15323.      5068.       5068.    20657.     35980.           5996.60   (LOWEST)

    7              758.        758.     15742.      5718.       5718.    26375.     42117.           6016.71
    8              488.        488.     16012.      6368.       6368.    32744.     48755.           6094.40
    9              315.        315.     16185.      7018.       7018.    39762.     55947.           6216.38
   10              203.        203.     16297.      7669.       7669.    47430.     63728.           6372.79
••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••

   11              130.        130.     16370.      8319.       8319.    55749.     72119.           6556.23
   12               84.         84.     16416.      8969.       8969.    64718.     81134.           6761.14
   13               54.         54.     16446.      9619.       9619.    74337.     90782.           6983.26
   14               35.         35.     16465.     10269.      10269.    84605.    101071.           7219.32
   15               22.         22.     16478.     10919.      10919.    95524.    112002.           7466.79
••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
  MINIMUM AVERAGE COST PER PERIOD = $   5996.60    BEST REPLACEMENT CYCLE  =    6 TIME PERIODS
••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
FOR REPLACEMENT POLICY   1 PERIODS LONGER, PENALTY COSTS =  $    20. PER VEHICLE PER PERIOD
FOR REPLACEMENT POLICY   2 PERIODS LONGER, PENALTY COSTS =  $    98. PER VEHICLE PER PERIOD
FOR REPLACEMENT POLICY   3 PERIODS LONGER, PENALTY COSTS =  $   220. PER VEHICLE PER PERIOD
FOR REPLACEMENT POLICY   4 PERIODS LONGER, PENALTY COSTS =  $   376. PER VEHICLE PER PERIOD

(*) - NOTE THAT THIS COLUMN DIFFERS
      ONLY IF AN INTEREST RATE IS USED
```

Figure A.3   LIFETIME Program Output.

```
                                                 CITY OF SAMPLEVILLE
                                            VEHICLE REPLACEMENT ANALYSIS

FOR THIS SET OF CALCULATIONS, AN INTEREST RATE OF      0.0    WAS USED
LIFE =   6.0

FOR TYPE 1001 LOW LIM =   608.405 HIGH LIM =   759.150 DEPRECIATION RATE = .440
VEHICLE NO. 90090C999 T VALUE =      4.911
VEHICLE NO. 900900999 AFTER  B YEARS, B =   944. *** VALUE ABOVE TYPE 1001 AVERAGE.- CHECK EXPENSES

NEW LIFETIME WILL BE    4.6 YEARS, IF PRESENT TREND IN O AND M COST CONTINUES
```

Figure A.4   TRENDS Program Output.

```
                                          CITY OF SAMPLEVILLE
                                     VEHICLE REPLACEMENT ANALYSIS
                                    TABLE OF ECONOMIC REPAIR LIMITS

VEHICLE TYPE 1001     AVG. COST PER PERIOD  = $  5997.0

INTEREST RATE = 0.0    ECONOMIC LIFETIME CYCLE =  6 PERIODS

                                    PREDICTED REPAIR LIMITS

               ZERO SALVAGE         25% SALVAGE         50% SALVAGE         75% SALVAGE
PERIODS
TO PLANNED        REPAIR         SALVAGE  REPAIR     SALVAGE  REPAIR     SALVAGE  REPAIR
REPLACEMENT       LIMIT          VALUE    LIMIT      VALUE    LIMIT      VALUE    LIMIT

     5            11145.          2657.    8931.      5314.    6717.      7970.    4503.

     4             7616.          1711.    6475.      3422.    5335.      5133.    4194.

     3             4737.          1102.    4186.      2204.    3635.      3306.    3084.

     2             2508.           710.    2271.      1420.    2035.      2129.    1798.

     1              929.           457.     853.       914.     777.      1371.     700.
```

Figure A.5   REPAIRLM Program Output.

APPENDIX B

ECONOMIC VEHICLE ASSIGNMENT/REPLACEMENT MODEL

Mr. B. G. Mattimore (Management Engineering Branch Head, Public Works Center Industrial Management Division, NAVFACENGCOM DET San Diego, California) has developed an economic based model intended to assist transportation managers in minimizing the costs of operating their vehicle fleets. This model clearly illustrates the need to examine the costs incurred by individual vehicles in order to make cost effective assignment or replacement decisions.

The following simplifying assumptions were incorporated in the model's development:

- Operating costs (fuel) of new vehicle equal the Operating costs of old vehicle
- Maintenance costs are much more dependent on a vehicle's mileage than age
- A simple straight line formula is required to determine target maintenance costs per mile

Historical maintenance data were obtained from a joint Office of Management and Budget/General Services Administration (OMB/GSA) study of GSA sedans [Ref. 32]. These data were utilized to derive a basic formula for target maintenance costs per mile (CPM). This formula, illustrated by Figure B.1, accounts for both the effects of the mileage incurred for the year of service as well as the vehicle's total accumulated mileage.

The formula provides a reasonable prediction of maintenance costs per mile when compared to the historical computations as shown by Figure B.2 This information can be used to illustrate the effect that an activity's vehicle assignment policy can have on expected maintenance costs.

$$\frac{\text{Starting Mi.} + \text{Ending Mi.}}{2} \times \frac{1}{1{,}000{,}000} = \text{CPM}$$

Figure B.1 Maintenance CPM for Sedans.

Service Year	Ave Annual Mi/Vehicle	Ave Accum Mi/Vehicle	GSA Maint Cost/Mi	From Formula
1	14,927	14,927	.0101	.0075
2	14,720	29,647	.0228	.0223
3	13,966	43,613	.0372	.0366
4	11,481	55,094	.0449	.0494
5	9,189	64,283	.0464	.0597
6	8,825	73,108	.0456	.0687
Average	12,185		.0322	.0366

Figure B.2 Historical vs. Derived Maintenance CPM.

Consider a situation where a manager has a fleet of two vehicles, one with an accumulated mileage of 10,000 miles, and the other with an accumulated mileage of 100,000 miles. The manager has requirements to assign the vehicles to different users who historically have put respectively 2,000 and 30,000 miles on their vehicles annually. If the manager were to budget his maintenance costs for the year based upon the averages shown in Figure B.3, the expected cost would be $ 2,016. However, as shown by Figure B.4, by considering the vehicles and the individual combinations of their potential assignments the predicted total maintenance costs

	VEHICLES			ASSIGNMENTS
1.	Accum Miles	10,000	1.	2,000 miles
2.	Accum miles	100,000	2.	30,000 miles
	Averages:	55,000		16,000

$$\text{Target CPM} = \frac{55{,}000 + 71{,}000}{2} \times \frac{1}{1{,}000{,}000} = .063$$

.063 x 16,000 mi = $ 1,008/vehicle x 2 =$ 2,016 Total

Figure B.3 Expected Maintenance Costs Using Averages.

drastically change from a minimum of $ 902 to a maximum of $ 3,472. The application of assigning the lowest cost per mile vehicle to the highest mileage user to minimize expected maintenance costs can be further taken to the larger fleet application and utilized in the decision-making process for vehicle replacements.

START MI	END MI	TARGET CPM	MI/YR	COST
10,000	40,000	.025	30,000	$ 750
100,000	102,000	.101	2,000	202
			Total =	$ 902

START MI	END MI	TARGET CPM	MI/YR	COST
100,000	130,000	.115	30,000	$ 3,450
10,000	12,000	.011	2,000	22
			Total =	$ 3,472

Figure B.4 Vehicle Assignment Has An Effect.

In order to utilize the model for replacement decisions, the total cost of the new vehicle must be compared with that of the old vehicle. Consideration of the capital costs of each vehicle must now be utilized as part of the analysis. This model assumes straight line depreciation on the basis of the current DOD six year age criteria for sedans. Figure B.5 illustrates that as vehicles with the highest maintenance cost per mile are replaced with new vehicles, the total expected maintenance costs for the fleet continue to decline. However, the effects of the capital costs on the anticipated total cost for the year soon overcome the maintenance cost reductions. The point at which the optimum number of replacement vehicles is attained is where the total annual cost is the minimum. It should be noted that Figure B.5 was developed utilizing the lowest cost per mile vehicles assigned to the highest mileage users, and that while the new vehicles were costed at the target cost per mile rates the old vehicles were costed at their current cost per mile rates.

Previous illustrations utilized data from sedans. Multiplier factors have been derived from historical data, as shown by Figure B.6, to establish target maintenance costs per mile for use of this model with other types of transportation equipment.

```
ORIGINAL FLEET:

                       ANNUAL              MAINT              TOTAL
   USN        YR       MILES      CPM      COST      DEPR     COST
---------     --       -----     -----     -----     -----    -----
94-89885      73        2424     1.395     3,381        00    3,381
94-87829      71        2732      .347       948        00      948
94-87831      71        2884      .236       681        00      681
94-94159      75        3232      .234       756        00      756
94-94191      75       10736      .176     1,890        00    1,890
94-09486      81       10848      .018       195     1,345    1,540
94-87830      71       11132      .003        33        00       33
                                           -----              -----
                    TOTALS =             $ 7,884            $ 9,229

REPLACING MOST EXPENSIVE TO OPERATE VEHICLE:

                       ANNUAL              MAINT              TOTAL
   USN        YR       MILES      CPM      COST      DEPR     COST
---------     --       -----     -----     -----     -----    -----
94-87829      71        2424      .347       841        00      841
94-87831      71        2732      .236       645        00      645
94-94159      75        2884      .234       675        00      675
94-94191      75        3232      .176       569        00      569
94-09486      81       10736      .018       193     1,345    1,538
94-87830      71       10848      .003        33        00       33
XX-XXXXX      **       11132      .008        89     1,012    1,101
                                           -----              -----
                    TOTALS =             $ 3,045            $ 5,402

REPLACING TWO MOST EXPENSIVE TO OPERATE VEHICLES:

                       ANNUAL              MAINT              TOTAL
   USN        YR       MILES      CPM      COST      DEPR     COST
---------     --       -----     -----     -----     -----    -----
94-87831      71        2424      .236       572        00      572
94-94159      75        2732      .234       639        00      639
94-94191      75        2884      .176       508        00      508
94-09486      81        3232      .018        58     1,345    1,403
94-87830      71       10736      .003        32        00       32
XX-XXXXX      **       10848      .008        87     1,012    1,099
XX-XXXXX      **       11132      .008        89     1,012    1,101
                                           -----              -----
                    TOTALS =             $ 1,985            $ 5,354

REPLACING THREE MOST EXPENSIVE TO OPERATE VEHICLES:

                       ANNUAL              MAINT              TOTAL
   USN        YR       MILES      CPM      COST      DEPR     COST
---------     --       -----     -----     -----     -----    -----
94-94159      75        2424      .234       567        00      567
94-94191      75        2732      .176       481        00      481
94-09486      81        2884      .018        52     1,345    1,397
94-87830      71        3232      .003        10        00       10
XX-XXXXX      **       10736      .008        86     1,012    1,098
XX-XXXXX      **       10848      .008        87     1,012    1,099
XX-XXXXX      **       11132      .008        89     1,012    1,101
                                           -----              -----
                    TOTALS =             $ 1,372            $ 5,753
```

Figure B.5 Vehicle Replacement Application.

	HISTORICAL		
	GSA	NAVY	MULTIPLIER
Sedan/Station Wagon	1.0	1.0	1.0
Buses	1.9	2.76	2.5
Up to 1 Ton	1.5	1.25	1.5
1-1/2 to 5 Ton	3.3	2.0	2.5
5 Ton & Over	3.5	4.1	4.0

Figure B.6 Multipliers For Maintenance Cost Per Mile.

APPENDIX C

PROJECT BEST

BEST is the name of an ongoing NAVFACENGCOM sponsored project to provide a computerized management system for Public Works Departments. The system is intended to be comprised of four basic software packages, or modules, which are presently in various stages of development and implementation, and is designed to assist medium-sized and larger activities in the Housing, Maintenance and Utilities, Planning and Estimating, and Transportation areas. While 81 activities are currently programmed to receive at least some of the modules, only 50 locations are planned to receive the Transportation module. Criteria for receiving this module are a minimum population of 300 pieces of equipment and an activity's willingness to fund its installation.

The prototype transportation module undergoing testing at the Naval Air Station, Miramar, California was examined as part of the research for this thesis to learn more about its potential for future use with the proposed vehicle replacement model [Ref. 33].

The module includes the following four segments:

- Administration: Contains the activity's equipment inventory and pertinent statistics, such as vehicle USN number, ECC, year, make, model, procurement contract number, delivery date, purchase cost, etc.
- Operations: Provides controls for dispatching of vehicles and vehicle assignments.
- Maintenance: Provides controls for generating SFO's, assigning and tracking work, monitoring downtime, tracking direct labor and material costs, and monitoring vehicle maintenance and repair history.

- Fuel System: Interacts with the Fuel Automated Data System (FADS) to be installed at each activity to input daily fuel transactions and monitor fuel consumption.

The reports which can be generated by this module can be stratified to individual USN numbers and have the ability to display maintenance and repair costs for the life-to-date of the vehicle, the previous fiscal year, the current fiscal year-to-date, the past six month period, the current month, and for each of the past 13 months. Although there is much flexibility in the system's ability to sort and display the information, the ability to retain a vehicle's maintenance and repair costs for each year of age does not exist past the previous fiscal year. As with the Public Works Center Transportation Management System, retention of that data would be accomplished through generation of year end reports in hard copy form or through the implementation of additional steps to provide a means of electronic storage and retrieval.

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